METALS & ALLOYS

Registered in the U. S. Patent Office

The Magazine of Metallurgical Engineering

INCLUDING METALLURGICAL ABSTRACTS

VOLUME 2

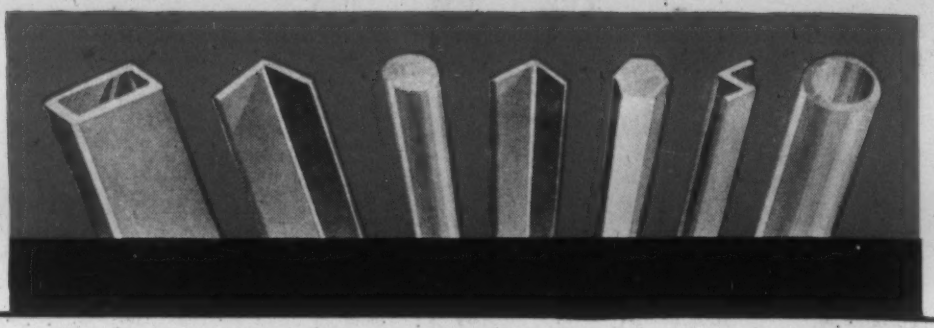
$3.00 a Year

OCTOBER
1931

NUMBER 4

$1.00 a Copy

Now



INDUSTRY'S LIGHTEST METAL IN WIDE VARIETY OF SHAPES AT NEW LOW PRICES

NOW you can use ultra light Dowmetal alloys in *your* products. Improved Dow processes have put this wonderful metal on a commercial basis. Selling but a few years back at $5.00 per pound, these magnesium alloys may now be had in steady supply and large quantities at 30c per pound.

Try Dowmetal for objects which men have to carry and move frequently, such as foundry flasks, ladders, heavy duty tools, vacuum cleaners, typewriters, etc.

Since Dowmetal is less than one-fourth the weight of steel and much lighter even than aluminum, products can now be reduced to a small part of their present weight, a sales feature worth considering.

Strong, enduring Dowmetal alloys machine easily—as a rough comparison, about three times as rapidly as cast iron. They are especially adapted to rollers and turned shapes. The metal is readily welded, forged, extruded, rolled and cast by methods common to industry. Standard shapes and sheets as well as ingots are available for prompt shipment. Improve your products by removing excess weight. Get your copy of the new Dowmetal data book.

Dowmetal Division

THE DOW CHEMICAL COMPANY
Midland, Michigan

Now You Can
Make it of Dowmetal

Take useless dead weight out of your product

1/4 THE WEIGHT *of* STEEL
•
MACHINES EASILY
•
GOOD MECHANICAL PROPERTIES
•
DURABLE . . .

DOWMETAL
MAGNESIUM ALLOYS

METALS & ALLOYS

The Magazine of Metallurgical Engineering

H. W. GILLETT, Editorial Director
Battelle Memorial Institute,
Columbus, Ohio

RICHARD RIMBACH, Editor

EDITORIAL OFFICE:
3619 Forbes St., Pittsburgh, Pa.

All Editorial correspondence should be sent to the above address

◆

Editorial Advisory Board

H. A. ANDERSON
Western Electric Company
W. H. BASSETT
American Brass Company
A. L. BOEGEHOLD
General Motors Corporation
P. H. BRACE
Westinghouse Electric & Mfg. Co.
R. A. BULL
Electric Steel Founders' Research Group
O. W. ELLIS
Ontario Research Foundation
JUNIUS D. EDWARDS
Aluminum Company of America
H. J. FRENCH
International Nickel Company, Inc.
S. L. HOYT
A. O. Smith Corporation
J. B. JOHNSON
Wright Field, Air Corps, War Department
JOHN JOHNSTON
United States Steel Corporation
JAMES T. MACKENZIE
American Cast Iron Pipe Company
JOHN A. MATHEWS
Crucible Steel Company of America
C. A. McCUNE
Welding Engineering & Research Corporation
W. B. PRICE
Scovill Manufacturing Company
H. A. SCHWARTZ
National Malleable & Steel Castings Company
F. N. SPELLER
National Tube Company
L. W. SPRING
Crane Co.
JEROME STRAUSS
Vanadium Corporation of America

◆

WM. P. WINSOR, Advertising Manager

ADVERTISING OFFICES:
MAIN OFFICE, 3619 Forbes St., Pittsburgh.
CHICAGO, 1050 Straus Bldg.
CLEVELAND, 953 Leader Bldg.
NEW YORK, 419 Fourth Ave.
SAN FRANCISCO, 381 Bush St.

◆

PUBLISHED MONTHLY BY THE CHEMICAL CATALOG COMPANY, INC.

Francis M. Turner, Pres.
H. Burton Lowe, Vice-Pres.
Howard Myers, Vice-Pres.
R. W. Reinhold, Secy.-Treas.

◆

Annual Subscription: U. S., Possessions, Mexico and Cuba, $3.00; All Other Countries, $4.00.

All communications relating to subscriptions or back issues should be addressed to METALS & ALLOYS, 419 Fourth Avenue, New York.

Copyright, 1931, by The Chemical Catalog Company, Inc. All rights reserved.

CONTENTS—OCTOBER, 1931

Oxidation—A Cause of Porosity in Leaded Bronze . . . 181
E. Doughty

Vacuum Casting 184
H. T. Reeve

A Suggested Method of Determining the Cleanness of a Heat of Steel 186
Samuel Epstein

Pouring Practice for Avoidance of Defects in Aluminum Ingots for Rolling 192
G. L. Craig

Centrifugal Casting of Metals and Alloys 197
J. E. Hurst

Metal Foil Applications 206
R. P. Stranahan

Securing Quality in Steel Plate 209
J. Stewart Huston

Testing Deep Drawing Qualities of Sheet Metal 214
H. W. Gillett with discussion by C. L. Eksergian

Effect of Molybdenum on Graphitization of White Cast Iron . 223
W. H. Jennings, Jr. and E. L. Henderson

Shot Gun Explosion Mystery Solved by Metallography . . 226
Oscar E. Harder

Mechanical and Creep Properties of Molybdenum Cast Iron . 229
C. H. Lorig and F. B. Dahle

Use of Bismuth in Metal Forming 236
Walter C. Smith

A New Aluminum Alloy 238
T. W. Bossert and J. A. Nock, Jr.

Electrical Resistivity of Certain Copper Alloys in the Molten State 240
C. S. Williams

The Influence of Impurities in Foundry Brasses and Bronzes . 242
H. M. St. John

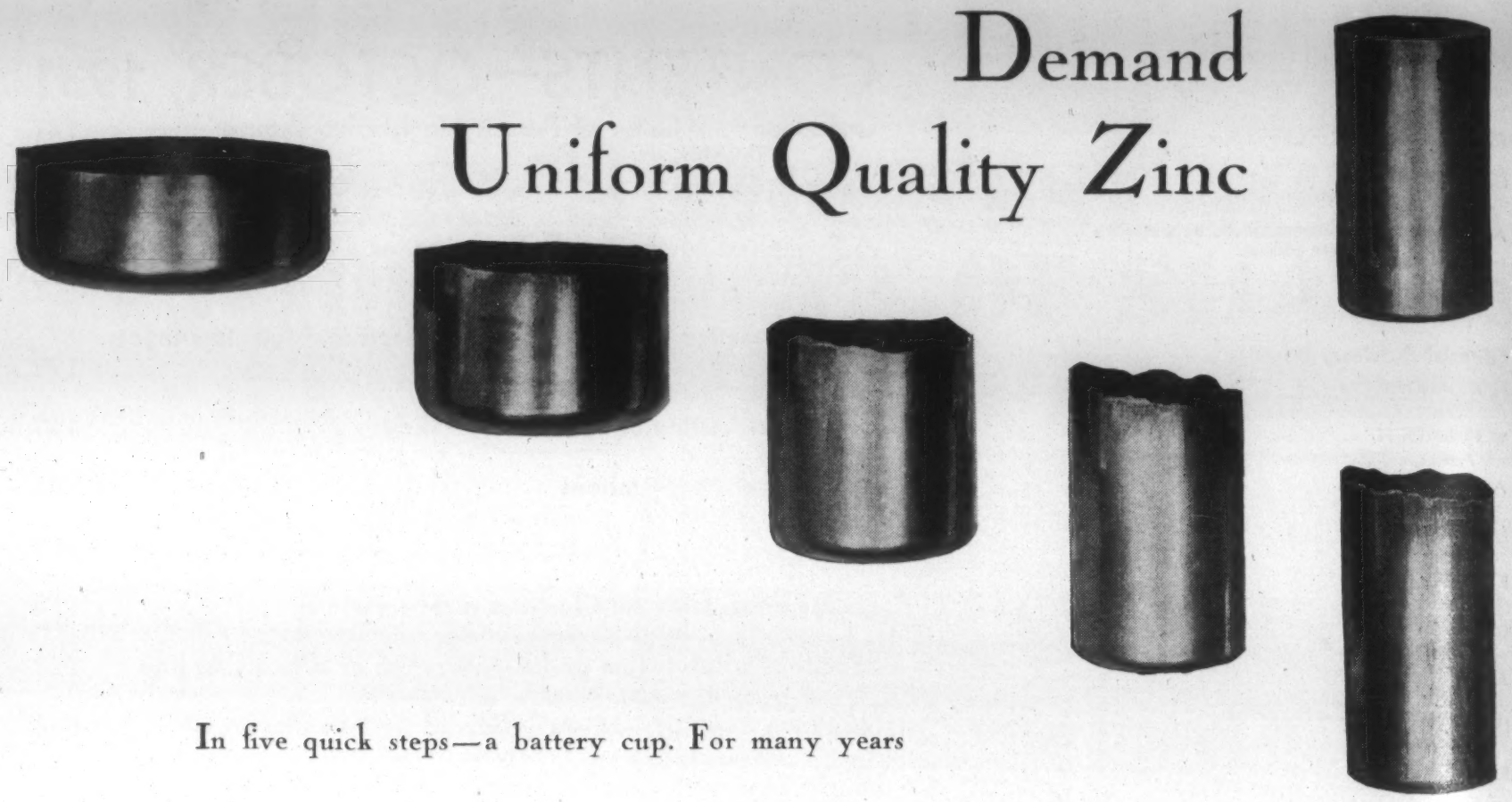
Preferred Orientation Produced by Cold Rolling in the Surface of Sheets of Aluminum, Nickel, Copper and Silver . . . 246
Cleveland B. Hollabaugh and Wheeler P. Davey

Editorial Comment . . . 177 **Readers' Comments** . . 180

METALLURGICAL ABSTRACTS

General 203
Properties of Metals 203
Properties of Non-Ferrous Alloys 205
Properties of Ferrous Alloys 205
Corrosion, Erosion, Oxidation, Passivity & Protection of Metals & Alloys . 207
Structure of Metals & Alloys 209
Physical, Mechanical & Magnetic Testing 213
Electro-Chemistry 216
Metallic Coatings Other than Electroplating 217
Industrial Uses and Applications 218
Heat Treatment 219
Joining of Metals & Alloys 221
Defects 225
Chemical Analysis 225
Working of Metals & Alloys 224
Historical & Biographical 226
Economic 226
Plants & Laboratories 226
Machinery & Supplies 227
Bibliographies 227
Miscellaneous 227
Foundry Practice & Appliances 228
Furnaces & Fuels 230
Refractories & Furnace Materials 230
Gases in Metals 230
Effects of Elements on Metals & Alloys 230
Effect of Temperature on Metals & Alloys 231
Leaching 232
Reduction Metallurgy 232
Non-Metallic Coatings for Metals & Alloys 233

Heavy Production Schedules Demand Uniform Quality Zinc



In five quick steps—a battery cup. For many years

The New Jersey Zinc Company's High Grade Deep Drawing Rolled Zinc has been the standard material for the leading dry battery manufacturers.

As the lowest cost non-ferrous metal, Zinc has many advantages in other industries. The uniform quality of The New Jersey Zinc Company's Zinc products makes them indispensable materials in large production schedules.

Have you reviewed the qualities of Zinc and Zinc Alloys with your own requirements in mind?

The New Jersey Zinc Company

160 Front Street — New Jersey zinc — New York City

EDITORIAL COMMENT

The Forming of Metals

The ultimate user is directly concerned with the strength, wear resistance, corrosion resistance, appearance, etc. of the metal parts he makes use of. These properties affect the useful life, and he can see their importance. There is another property concealed in those metal parts which is reflected in the price he pays for the finished parts, and that property is formability. In general, this property is not easily measured or appraised.

Whether the part is shaped into finished form by a major operation of machining or grinding with the removal of much metal, or whether it is made almost or quite to size by previous operations in which metal has not been removed, but has been made to flow into the desired form, makes a whole lot of difference in the cost, for machining of any type is a relatively expensive operation.

If we allow molten metal to flow into a mold, and freeze it in the desired form or as near to it as possible, in a sand mold, a permanent mold, or a die casting, it is a great asset if the metal will flow into fine crevices and sharply reproduce the pattern, and if it will freeze with a structure of proper strength properties, and free from blowholes, cracks and shrinkage voids or pipes. And if it will set with so smooth a surface that machining can be avoided or minimized, it makes a lot of difference in the final cost. Hence, interest in the control of foundry sand mixtures so as to give better surface, in the "runability" and the solidification shrinkage of metals, is increasing.

The suitability of an alloy for casting is something the foundryman never forgets, and many alloys that would have desirable properties if they could be more easily cast, find little use because of casting difficulties.

In many cases, the original molten metal is cast, not in any relation whatever to a particular finished part, but as an ingot for rolling, forging, drawing or similar forming, hot or cold, with the idea of making the solid metal flow, by exercise of stress upon it, into some form that has one standard dimension. Thus plates are rolled to thickness, and are trimmed to size, wire is drawn to diameter, and rails are rolled and shapes extruded to give the cross-sectional shape wanted. These operations are carried out on a huge scale, and are much more cheaply done in bulk than if each part were cast to shape. Articles of uniform cross-section naturally tend to be made from such products.

When articles of highly irregular or variable section are to be made, forging, die pressing, stamping, etc., perhaps with assembly by welding, compete with casting.

Whatever the method of forming may be, whether casting by fluid flow or deformation by plastic flow, the ability of the material to be formed bulks large in the mind of the fabricator and in his cost sheets. It is going to be progressively necessary for the engineer to devise more economical methods of forming, and for the metallurgist to study his alloys more closely as to their suitability for forming.

There is a field for alloys suitable for cold forming which are given superior properties by virtue of the grain refinement due to cold work so that heat treatment is not required.

Metallurgical courses in general pay less attention to the principles of and the methods of determination of formability, than they do to the properties of the finished product, largely because the professors are not thoroughly in touch with shop practice, but the minute a budding metallurgist gets into the shop, he begins to meet formability problems. He will often find that specifications for the materials he uses do not adequately evaluate formability which makes it necessary to put more dependence on brand, or buy from a given supplier in order to get uniformity in formability. This is a situation that ought not to obtain in this day and age, but it does obtain.

No production engineer engaged in casting and forming can himself be conversant, from his own experience, with all the ingenious means of cost-cutting that are being worked out in these fields, nor can the metallurgist find in reference books all the information he needs in avoiding impurities harmful to formability and in modifying alloys to improve it. Most of the help has to come from current technical literature.

In this issue, we have collected articles dealing with various phases of casting and of plastic forming. The field is, of course, too large to cover in a single issue. We should be glad to have other authors send in articles along this line for future issues.

NO METAL cover this month! Sorry to disappoint those of our readers whose interest was aroused by our September cover, but the manufacturer who was to supply the material met with unforeseen delays in its production. Not that this manufacturer "fell down" on his promise, but the experiments which we are now conducting on printing directly on metal required an unusually early date of delivery of samples identical with the foil ordered. We can safely promise, however, that the November issue of this metallurgical engineering magazine will fittingly be clad in metal.

Crime's Strongest Ally?

It is difficult for a scientific man to understand the law's vacillations and the strange ignoring of plain facts which is exhibited in certain cases. To the scientific man, facts are facts, and, as such, are to be accepted without reservation, and, so far as new scientific truths are concerned, are accepted with a joy that men of other training have trouble in understanding.

While it must be recognized that human affairs and relationships are considerably different from matters obtaining in the world of the metallurgist and physicist, it is improbable that some of the apparent misuses now existing in the law courts could long exist if judges and lawyers used as far as practicable the scientific man's "fact" yardstick and attitude. That a man is guilty, proved so, and is so even by his own admission may mean nothing in law if some technical provision of legal procedure has been contravened.

When reading of the crimes recorded in the papers and the apparent present inability of the law to cope with them, the scientific man thinks of the difference in attitude of the two professions—Law and Science. The one reveres the past and trembles at establishing "precedent." To the other, past and "precedent," as such are inconsequental; but fundamentals, and, when proved, the acceptance of new truths not only are not feared but are positively alluring. The scraping of outgrown and untrue theories and conceptions causes little pain to the true scientist, but instead is pleasurable. Verily, if the scientific man ever assumed responsibility for legal form and procedure, the wreckage of established custom in that profession might be appalling.

A thoughtful professor of science in one of our great universities was discussing this subject with us recently. He said that one of the things that distresses the conscientious leaders of the legal profession is the fact that a considerable proportion of applicants for admission to the bar is, in the main, of foreign extraction, smart as a whip, capable of passing any examination that might be set, but lacking in complete moral sense. Of such material is counsel for gangsters made, and there seems to be no existing means for preventing its admission to the bar.

Contrast this with the intellectual integrity and probity of the candidates for degrees in scientific courses. Certainly there are few metallurgical crooks, and when one does appear, he does not enjoy the admiration of others in his profession. The adjective "shrewd" is applied to lawyers by lawyers as a complimentary term, but when a metallurgist uses it in reference to another metallurgist, it is considered highly uncomplimentary.

L. W. S.

◆ ◆ ◆

Elinvar in Use

Engineers have long been acquainted with the properties of Invar, the nickel iron alloy which has practically zero coefficient of expansion over a certain range of temperature. The public became acquainted with it due to its use in the strut type of aluminum pistons for automobiles.

Another alloy, Elinvar, developed by Guillaume, the distinguished horologist and Director of the International Bureau of Weights and Measures, in France, of iron, nickel and chromium, has, as its name indicates, an invariable modulus of elasticity, that is, its spring action is unchanged with reasonable temperature changes. This alloy was developed by Guillaume especially for use in watch-springs, to avoid deviations due to temperature changes. It is naturally rust-resistant, and it is of the austenitic type, hence, it avoids much of the trouble due to rusting and to magnetic effects. It is such a logical alloy for the purpose, and the cost of the material itself is so negligible, since there are 13,000 watch hairsprings to the pound, that metallurgists naturally assumed that horologists were using the alloy.

Not more than half a dozen years ago, we were talking to a group of American horologists about metallurgy, and in mentioning some of the things in metallurgy that were of interest to the watch maker, we said that of course, it was not necessary to deal with Elinvar for, of course, they were already well acquainted with its properties by their own use of it. However, we found that some of them had not even heard of it, and most of the others who had, appeared convinced that the older methods of compensation were quite adequate. Only a few showed any real interest.

However, we are informed that after a period of experimentation covering years, the Hamilton Watch Company and the Illinois Watch Company have decided that Elinvar hairsprings make it possible to produce watches with temperature compensation equal to or better than that obtained in the Standard Railroad grade, plus the other advantages of avoiding rust and the effect of magnetism.

They rate the use of Elinvar as one of the most revolutionary changes that alloy steel has caused in any industry.

Since it was nearly a dozen years ago that Guillaume received the Nobel Prize on the basis of his work on Elinvar among his other attainments, it seems odd that it should have taken so long for industry to utilize what the metallurgist has so long known about. We have previously commented on the fact that chromium plating was developed to a very workable stage by Sargent, was then brought to the attention of various manufacturers without arousing any interest, and lay dormant for years and years before it met commercial use.

Elinvar is just another case of an alloy of peculiar properties fitting a peculiar need and finally being put to its logical use. We wonder whether the conservatism that made utilization so slow in the cases cited is still with us in the present day, or whether it vanished a decade ago. Newer developments, such as nitriding, seem to arouse more popular interest, and filter into actual use to-day at a more rapid rate, but we suspect that the conservatives are still pretty numerous. However, as soon as one progressive shows the way by actual use of hitherto unused material, the conservatives follow suit pretty promptly.

H. W. G.

The Cheap Alloying Elements for Steel

It is an odd fact that the metallurgy of the more expensive alloying elements in steel, such as nickel, vanadium and molybdenum, is more fully and definitely known than that of the cheap ones. Nickel and vanadium, particularly have been pushed by the strong firms producing them as a result of very detailed study to find out just where these elements are and are not applicable.

With most of the cheaper elements, there has been less centralization of the source of supply, so that the development of their possibilities and limitations has been everybody's business, and hence, nobody's business. We are not referring to Hadfield manganese steel, stainless, "18 and 8," or other highly alloyed steels, which, of course, have had intensive study, or to specialties like nitriding steels, but to "common or garden variety" structural and other steels with, say, one-half to one percent of alloying element.

There are signs that this situation is improving. The cheap elements chromium, manganese, silicon, copper and aluminum are moving up from the wings to a position nearer the center of the stage, even though the spot-light is not yet focused upon them.

The old silico-manganese spring steels, despite well-known drawbacks, have found continued use by those willing to humor their idiocyncrasies. Manganese has come to the fore in the medium-manganese steels, carrying up to one percent of alloying manganese over that required for controlling oxygen and sulphur. This too, has its idiocyncrasies, especially an abhorrence for being associated with too much carbon. Chromium has, of course, had a good deal of specific attention, both by itself and in conjunction with other elements.

Silicon, except for transformer steel, was pretty much left out of the picture until the German "Freund" steel agitation brought it more attention. The high silicon structural steel was the first big step in meeting the German desire for high yield stress, high ductility, structural steel. The dirtiness and the surface defects of this steel were so hard to avoid that the silicon was cut and the manganese boosted, thus following the leads of past American practice.

Recently it became quite evident that copper, in amounts beyond those in "copper-bearing" steels, adds to the physical properties, and the medium manganese, fairly high silicon steels plus copper are being considered.

The chromium-copper combination is now receiving much attention in Germany and other foreign countries. Various combinations of chromium, manganese, silicon and copper, with low carbon, will produce a structural steel with the yield stress of a higher carbon steel, with much better ductility.

Without doubt each of these steels have their own idiocyncrasies, and either large-scale production or exhaustive research will be required to select the most useful compositions.

At the moment there is active interest in this country in the "cromansil" steels, which may roughly be described as $1^1/_4\%$ Mn, medium manganese steels, plus $^3/_4\%$ Si, and $^1/_2\%$ Cr, with variations in these elements and in carbon (0.10–0.65%) as called for by the particular application in hand. These are now being described in detail in trade literature put out by the Electro-Metallurgical Company, after much study of the proper balance of composition. Each element has been called upon to supply its quota of properties, with as much attention to "fool-proofness" in manufacture and fabrication, as in final properties.

It is claimed that such steels with proper carbon content are valuable as rolled, normalized, normalized and tempered or heat-treated. One particularly interesting claim is that the endurance ratio of the low-carbon product is as high as 60%.

In heat-treated products, a combination of high strength and high impact, and good depth hardening properties are claimed. Welding properties are said to be equal to those of a plain carbon steel, and in the medium carbon grades, the material is free from air-hardening difficulties.

It is also said to be suitable for casting, especially with the addition of 0.10% V. Detailed information on these and many other points are available in the trade literature.

As yet, no one appears to be doing a similar job in the study of cheap-alloy, low-alloy steels of this type plus copper, and it would seem logical for the next step to be along that line.

Another element, whose proper place in steel is still too little known, is aluminum. The fear of alumina inclusions naturally deters its use, but it is a question whether, for some uses, heavy killing of steel with aluminum, properly performed on steel in condition to receive it, may not bring more advantages than evils. We look forward to the time when steel makers will advertise their special aluminum-treated steels, rather than admitting only with reluctance that they have any aluminum in their plant at all. Aluminum for scavenging steel is doubtless a bad master, but it may be a good servant. Whether a further alloying addition will prove useful remains to be seen.

The Vanadium people have long appreciated the importance of getting a tenth of a percent or so of that element into a large tonnage of steel. The Nickel and the Molybdenum people are finding that while in many grades of steel, only a relatively small amount is needed to confer the characteristic benefits of those elements, the wider opportunities for use of cheap but efficient steels bring the total tonnage of alloying element up to a respectable figure.

Complex "Irish-stew" alloys, in which a lot of elements are thrown together without good reason, are an abhorrence but a complex alloy in which each element is used in a definite amount for a definite purpose is quite another thing. As the alloys get more complex, experimentation becomes more time-consuming and expensive, due to the large number of variables involved. Without the sales urge that has been behind the work on the more expensive elements, the cheaper elements have lagged behind. But ultimately, whether the elements used are cheap or dear, the relation of attainable properties to cost will be the governing factor.

It is a healthy sign that more attention is being paid to the cheap elements, and while the metallurgical engineer may have a subconscious feeling that an element should be more potent if it is rare and costly, the steel itself has no such inhibition. H. W. G.

READERS' COMMENTS

WHAT IS THE BEST POURING TEMPERATURE FOR A GENUINE BABBITT?

EDITOR METALS & ALLOYS:

History teaches us that disagreements between nations have often lead to war. Disagreements between scientists or research workers result generally in investigations and final agreement. Hoping that his lines will precipitate comment and discussion among interested readers and bring forth new or unpublished data that eventually will lead to finality, the writer has collected the following information.

Though genuine babbitts have been in use for a good many years widely different pouring temperatures are being used by various research workers and manufacturers for alloys of practically the same chemical composition. It is a well established fact that too high a pouring temperature makes metal oxidized and drossy and that a too low pouring temperature results in formation of seams and imprisonment of air and gas bubbles. In neither case is a satisfactory babbitt lining obtained. Between these two extremes there is a wide temperature range where good linings are produced. It is only logical to assume that there is an optimum at which the best lining, that is the lining with the longest life, is obtained.

One large company in this country recommends a pouring temperature of 460° to 490° C. (860° to 914° F.) for a genuine babbitt containing 85% tin, 10% antimony and 5% copper, and a preheating temperature of bearing shells and mandrels of 150° C. (302° F.) The instructions of another company, also in this country, for practically the same alloy are, that the babbitt shall be poured between 650° and 700° C. (1202° and 1292° F.) and the shells and mandrels preheated to about 150° C. Engineers of the former company claim, however, that linings poured at such high temperatures have considerably shorter life than those poured at the lower temperature.

Continental practice on the other hand favors not only a high pouring temperature but also a high preheating temperature of shells and mandrels. The writer remembers this from his practical experience of over a decade ago, although he is unable to furnish data as to the temperatures employed. In an investigation published by H. Graefe of the Siemens Schuckert Works in *Maschinenbau* for Oct. 1927 (page 1001) a pouring temperature of 650° C. (1202° F.) and a preheating temperature of 500° C. (932° F.) for bearing shells and mandrels are recommended for a genuine babbitt containing 79% tin, 6.80% copper and 14.20% antimony.

The difference in chemical composition between the American and the German alloy can hardly account for any marked difference with regard to pouring or preheating temperature. Neither is it probable that, other conditions being equal, there will be much of a difference in wear resistance between the American and the German alloy. In an investigation on wear resistance of bearing bronzes, H. J. French and co-workers found* that variations in chemical composition are much less important than the methods of casting, and there is little reason to believe that the same should not be true of genuine babbitts.

In a theoretically perfect bearing the load should be carried on a film of oil between the shaft and the bearing and the nature and properties of the bearing metal should therefore be immaterial. In actual practise however, such perfection is not realized and it becomes the duty of the bearing metal to minimize as far as possible the inevitable errors of adjustment and alignment. A bearing metal, therefore consists of hard crystals imbedded in a soft and plastic matrix. The hard crystals take the load and present faces with high resistance to wear, while the matrix holds the hard crystals and allows them to conform themselves to the shaft and its movement. Because of its softness the matrix wears down somewhat, and in the depressions thus formed the oil film finds its place. This condition of the oil film existing in the depressions of the surface is so characteristic of a bearing metal, that a bearing metal has been defined as "a metal capable of retaining a lubricant upon its bearing surface" (Report of Sub-Committee on Bearing Metals, A. S. M. E., 1919). The extent to which the lubricant can be held, so determinates the most valuable characteristic of a bearing metal.

It is well known among foundrymen, that castings poured at high temperatures have a coarse grain structure and tend to be porous. Such castings have poor mechanical properties when compared with dense, fine grained castings, but with regard to the capability of retaining oil the former may be better. It has actually been found by French and co-workers* that chill cast bearing bronzes (i. e., bronzes with a dense fine-grained structure) wear faster than sand cast bronzes of the same composition, which, as a matter of fact, have a more coarse structure.

* *Research Paper* No 13, U. S. Bureau of Standards.

Refinement of the grain structure of a sand cast bearing bronze can be brought about by the addition of nickel without changing the method of casting, and it is interesting to note that this also results in decreased resistance to wear. This has been found in an investigation published in the *Bureau of Standards Journal of Research* (Aug. 1930, page 349) and the writer can report similar results. Back in 1926, when the price of tin rose to 75 cents per pound and there was talk of a "tin-famine," the writer suggested the substitution of nickel for tin in the 80%, copper 10% tin and 10% lead bearing bronze. Preliminary tests showed that an alloy in which 3% tin was replaced by 2% nickel and 1% copper had a greater Brinell hardness and a finer grain structure and bearings of this alloy were put in service. The result was, however, that the nickel containing bearings had worn more than the regular. It may, therefore, be taken for granted, that a fine grained structure of a bearing bronze is less advantageous than a coarse grained one where resistance to wear is of prime importance.

Returning now to the genuine babbitts, experiments have proven, according to a private communication to the writer, that a dense fine grained structure brought about by forging cast linings gave very poor results. In line with what has been mentioned above with regard to bearing bronzes, it may also be expected that a dense fine grained structure, caused by pouring the babbitt at a low temperature will result in short life. Assuming then that a coarse grain structure is a necessary condition for long life of genuine babbitt linings the question arises how large the grains really should be. Obviously a pouring temperature of 650° C. and a mold temperature of 500° C. results in much coarser grains than a pouring temperature of 490° C. and a mold temperature of 150° C. It would be very interesting from a scientific standpoint and very useful from an engineering and practical standpoint to know which conditions, if any, should be preferred.

Sept. 21, 1931.

JAMES BRINN,
CHICAGO, ILL.

◆ ◆ ◆

CORRECTION

Malleable Iron—Recent Progress

Figs. 1 and 3 appearing on page 144 of the September issue of METALS & ALLOYS were interchanged. Fig. 1 is the structure of soft gray iron. Fig. 3 is the structure of hard iron before the anneal.

◆ ◆ ◆

International Foundry Exhibit

The International Foundry Exhibit and Congress was held from September 12th to 27th in Machinery Hall of the Milan Sample Fair, Milan, Italy. The exhibit was divided into several groups:

Group I—Raw Materials

Class 1—Ores, fuel, metals, alloys, flux, refractories.
Class 2—Sands, corebinders, sea-coal, blacks, and other materials generally used in foundry practice.

Group II—Castings

Class 3—Rough and finished castings.
Class 4—Artistic and ornamental castings.
Class 5—Machines in which the cast parts represent the principal element.

Group III—Foundry Equipment

Class 6—Melting and heat treatment, apparatus and ovens: (*a*) by combustion; (*b*) by electricity.
Class 7—Pattern, pattern plates, materials and equipment used in pattern shops.
Class 8—Foundry tools.
Class 9—Apparatus for sand treating.
Class 10—Molding machines.
Class 11—Pouring machines.
Class 12—Materials, tools and machinery for shaking out, cleaning, chipping and repairing castings.
Class 13—Hoisting and conveying apparatus and interdepartment transportation.
Class 14—Testing machinery, measuring apparatus, laboratory instruments and materials.
Class 15—Lighting, heating and ventilation.

Group IV

Class 16—Technical and professional schools.
Class 17—Technical literature.
Class 18—Foundry organization.

Oxidation—A Cause of Porosity in Leaded Bronze

BY E. DOUGHTY*

BECAUSE of their excellent bearing qualities, relative low costs and good machinability, many alloys of copper, tin and lead have been put on the market. Most of these combinations have lead contents above 10%, and in some as much as 25% is introduced. This high proportion of lead is of importance not only because of its cheapening effect but because of its improvement to bearing performance. Its presence, however, adds to founding a number of difficulties among which porosity sits well to the front. All bronzes are of course subject to porosity from the well-known causes, but the leaded bronze is peculiarly susceptible to one kind of porosity which is of particular interest, as it depends upon a sequence of two distinctly opposite reactions. In this regard the following may be of value to those encountering similar conditions.

Occasionally when fracturing a cored casting of high lead content there was found just under the skin of the metal surrounding the core a ring of holes ranging in size from pin points to 1/4 inch in diameter. The sections containing these holes were usually discolored yellow, red, brown or black. In severe cases and especially in the larger castings, the bubbles of gas forming these holes had floated up into the body of the casting, thus making the cope side the more porous. However, in no case did all the bubbles float; there were always enough left to form a more or less complete ring of holes around the core.

The first thought on seeing a porous casting of this type was that the core or molding sand or both contained excessive moisture or other gas-forming material, and with this idea in mind the permeabilities of the cores and molding sand were greatly increased. This had no effect in reducing the porosity. Practically every core binder on the market was then tried but success was so slight that it was evident the cause lay elsewhere than with the character of bonding material.

Occasionally a fracture would show gas entirely around the core except in a spot lying in contact with the graphite used in calking the core seam. However, blackening the entire core with graphite did not improve matters. Core washes of many kinds were then used with the idea of making the skin of the core gas tight, so the gas would be forced out at the ends where vents had been provided. None of these had any effect whatever toward reducing the percentage of scrap until one of plaster of Paris was tried. This plaster of Paris coating stopped most of the porosity, but not all of it. Acetic acid was then added to the plaster of Paris to delay setting but the whole was a very unsatisfactory procedure.

* Asst. Metallurgist, Federal Mogul Corporation.

As stated above, these holes when present at all were under the skin of metal adjacent to the core and only occasionally next to the molding sand. Therefore, where possible, green sand cores were tried in order to have the same sand surface on both the inside and outside of the casting. The porosity was stopped entirely in castings so cored. But while the use of small cores coated with plaster of Paris and large cores made of green sand would stop most of the porosity, such a procedure would not be practical on a conveyor system with heavy production.

In the above experiments both new and secondary metals were employed together with four types of furnaces, but no relation could be established between the porosity and any of these variables. Attention was then centered on chemical analyses and after a number were made, it became apparent that the porous phosphor bronze castings contained very small amounts of phosphorus, or none at all, and that in other bronzes usually containing small amounts of zinc, the defectives were practically free of that element. It was then a question if the presence of zinc or phosphorus prevented porosity by making gas less soluble. Accordingly three charges of virgin metal were melted in coke-fired crucible furnaces under heavy charcoal coverings. One was poured without additions of any kind, one with the addition of a small amount of phosphor copper and the other with about 1% zinc. All castings were sound, and after repeating the experiment with the same results, it was concluded that the absence of zinc or phosphorus was not the sole cause of the porosity. The evidence presented by the chemical analyses, however, pointed strongly to the absence of these elements as being at least a contributory factor, and as zinc and phosphorus are both strong reducing agents the effect of oxygen was next considered.

A charge of virgin metals, made up to the composition 80% copper, 10% tin and 10% lead, was melted without covering in an oil-fired revolving type furnace. This type of furnace was selected because of the ease with which its atmosphere may be controlled. During the melting operation the atmosphere was held as nearly neutral as possible, judging from the exhaust gases and the appearance of the metal surface, until just before pouring when a strongly oxidizing flame was thrown over the melt for about ten minutes. The first mold was poured with the metal just as it came from the furnace without additions of any kind. The second mold was poured of the same metal to which was added 0.1% phosphorus in the form of phosphor copper. The first mold or oxidized metal had the ring of holes around the cores. The second mold or phosphorized metal was sound in every respect except for a discolored spot or

READERS' COMMENTS

WHAT IS THE BEST POURING TEMPERATURE FOR A GENUINE BABBITT?

EDITOR METALS & ALLOYS:

History teaches us that disagreements between nations have often lead to war. Disagreements between scientists or research workers result generally in investigations and final agreement. Hoping that his lines will precipitate comment and discussion among interested readers and bring forth new or unpublished data that eventually will lead to finality, the writer has collected the following information.

Though genuine babbitts have been in use for a good many years widely different pouring temperatures are being used by various research workers and manufacturers for alloys of practically the same chemical composition. It is a well established fact that too high a pouring temperature makes metal oxidized and drossy and that a too low pouring temperature results in formation of seams and imprisonment of air and gas bubbles. In neither case is a satisfactory babbitt lining obtained. Between these two extremes there is a wide temperature range where good linings are produced. It is only logical to assume that there is an optimum at which the best lining, that is the lining with the longest life, is obtained.

One large company in this country recommends a pouring temperature of 460° to 490° C. (860° to 914° F.) for a genuine babbitt containing 85% tin, 10% antimony and 5% copper, and a preheating temperature of bearing shells and mandrels of 150° C. (302° F.) The instructions of another company, also in this country, for practically the same alloy are, that the babbitt shall be poured between 650° and 700° C. (1202° and 1292° F.) and the shells and mandrels preheated to about 150° C. Engineers of the former company claim, however, that linings poured at such high temperatures have considerably shorter life than those poured at the lower temperature.

Continental practice on the other hand favors not only a high pouring temperature but also a high preheating temperature of shells and mandrels. The writer remembers this from his practical experience of over a decade ago, although he is unable to furnish data as to the temperatures employed. In an investigation published by H. Graefe of the Siemens Schuckert Works in *Maschinenbau* for Oct. 1927 (page 1001) a pouring temperature of 650° C. (1202° F.) and a preheating temperature of 500° C. (932° F.) for bearing shells and mandrels are recommended for a genuine babbitt containing 79% tin, 6.80% copper and 14.20% antimony.

The difference in chemical composition between the American and the German alloy can hardly account for any marked difference with regard to pouring or preheating temperature. Neither is it probable that, other conditions being equal, there will be much of a difference in wear resistance between the American and the German alloy. In an investigation on wear resistance of bearing bronzes, H. J. French and co-workers found* that variations in chemical composition are much less important than the methods of casting, and there is little reason to believe that the same should not be true of genuine babbitts.

In a theoretically perfect bearing the load should be carried on a film of oil between the shaft and the bearing and the nature and properties of the bearing metal should therefore be immaterial. In actual practise however, such perfection is not realized and it becomes the duty of the bearing metal to minimize as far as possible the inevitable errors of adjustment and alignment. A bearing metal, therefore consists of hard crystals imbedded in a soft and plastic matrix. The hard crystals take the load and present faces with high resistance to wear, while the matrix holds the hard crystals and allows them to conform themselves to the shaft and its movement. Because of its softness the matrix wears down somewhat, and in the depressions thus formed the oil film finds its place. This condition of the oil film existing in the depressions of the surface is so characteristic of a bearing metal, that a bearing metal has been defined as "a metal capable of retaining a lubricant upon its bearing surface" (Report of Sub-Committee on Bearing Metals, A. S. M. E., 1919). The extent to which the lubricant can be held, so determinates the most valuable characteristic of a bearing metal.

It is well known among foundrymen, that castings poured at high temperatures have a coarse grain structure and tend to be porous. Such castings have poor mechanical properties when compared with dense, fine grained castings, but with regard to the capability of retaining oil the former may be better. It has actually been found by French and co-workers* that chill cast bearing bronzes (i. e., bronzes with a dense fine-grained structure) wear faster than sand cast bronzes of the same composition, which, as a matter of fact, have a more coarse structure.

* *Research Paper* No 13, U. S. Bureau of Standards.

Refinement of the grain structure of a sand cast bearing bronze can be brought about by the addition of nickel without changing the method of casting, and it is interesting to note that this also results in decreased resistance to wear. This has been found in an investigation published in the *Bureau of Standards Journal of Research* (Aug. 1930, page 349) and the writer can report similar results. Back in 1926, when the price of tin rose to 75 cents per pound and there was talk of a "tin-famine," the writer suggested the substitution of nickel for tin in the 80%, copper 10% tin and 10% lead bearing bronze. Preliminary tests showed that an alloy in which 3% tin was replaced by 2% nickel and 1% copper had a greater Brinell hardness and a finer grain structure and bearings of this alloy were put in service. The result was, however, that the nickel containing bearings had worn more than the regular. It may, therefore, be taken for granted, that a fine grained structure of a bearing bronze is less advantageous than a coarse grained one where resistance to wear is of prime importance.

Returning now to the genuine babbitts, experiments have proven, according to a private communication to the writer, that a dense fine grained structure brought about by forging cast linings gave very poor results. In line with what has been mentioned above with regard to bearing bronzes, it may also be expected that a dense fine grained structure, caused by pouring the babbitt at a low temperature will result in short life. Assuming then that a coarse grain structure is a necessary condition for long life of genuine babbitt linings the question arises how large the grains really should be. Obviously a pouring temperature of 650° C. and a mold temperature of 500° C. results in much coarser grains than a pouring temperature of 490° C. and a mold temperature of 150° C. It would be very interesting from a scientific standpoint and very useful from an engineering and practical standpoint to know which conditions, if any, should be preferred.

Sept. 21, 1931.

JAMES BRINN,
CHICAGO, ILL.

◆ ◆ ◆

CORRECTION

Malleable Iron—Recent Progress

Figs. 1 and 3 appearing on page 144 of the September issue of METALS & ALLOYS were interchanged. Fig. 1 is the structure of soft gray iron. Fig. 3 is the structure of hard iron before the anneal.

◆ ◆ ◆

International Foundry Exhibit

The International Foundry Exhibit and Congress was held from September 12th to 27th in Machinery Hall of the Milan Sample Fair, Milan, Italy. The exhibit was divided into several groups:

Group I—Raw Materials

Class 1—Ores, fuel, metals, alloys, flux, refractories.
Class 2—Sands, corebinders, sea-coal, blacks, and other materials generally used in foundry practice.

Group II—Castings

Class 3—Rough and finished castings.
Class 4—Artistic and ornamental castings.
Class 5—Machines in which the cast parts represent the principal element.

Group III—Foundry Equipment

Class 6—Melting and heat treatment, apparatus and ovens: (*a*) by combustion; (*b*) by electricity.
Class 7—Pattern, pattern plates, materials and equipment used in pattern shops.
Class 8—Foundry tools.
Class 9—Apparatus for sand treating.
Class 10—Molding machines.
Class 11—Pouring machines.
Class 12—Materials, tools and machinery for shaking out, cleaning, chipping and repairing castings.
Class 13—Hoisting and conveying apparatus and interdepartment transportation.
Class 14—Testing machinery, measuring apparatus, laboratory instruments and materials.
Class 15—Lighting, heating and ventilation.

Group IV

Class 16—Technical and professional schools.
Class 17—Technical literature.
Class 18—Foundry organization.

Oxidation—A Cause of Porosity in Leaded Bronze

BY E. DOUGHTY*

BECAUSE of their excellent bearing qualities, relative low costs and good machinability, many alloys of copper, tin and lead have been put on the market. Most of these combinations have lead contents above 10%, and in some as much as 25% is introduced. This high proportion of lead is of importance not only because of its cheapening effect but because of its improvement to bearing performance. Its presence, however, adds to founding a number of difficulties among which porosity sits well to the front. All bronzes are of course subject to porosity from the well-known causes, but the leaded bronze is peculiarly susceptible to one kind of porosity which is of particular interest, as it depends upon a sequence of two distinctly opposite reactions. In this regard the following may be of value to those encountering similar conditions.

Occasionally when fracturing a cored casting of high lead content there was found just under the skin of the metal surrounding the core a ring of holes ranging in size from pin points to 1/4 inch in diameter. The sections containing these holes were usually discolored yellow, red, brown or black. In severe cases and especially in the larger castings, the bubbles of gas forming these holes had floated up into the body of the casting, thus making the cope side the more porous. However, in no case did all the bubbles float; there were always enough left to form a more or less complete ring of holes around the core.

The first thought on seeing a porous casting of this type was that the core or molding sand or both contained excessive moisture or other gas-forming material, and with this idea in mind the permeabilities of the cores and molding sand were greatly increased. This had no effect in reducing the porosity. Practically every core binder on the market was then tried but success was so slight that it was evident the cause lay elsewhere than with the character of bonding material.

Occasionally a fracture would show gas entirely around the core except in a spot lying in contact with the graphite used in calking the core seam. However, blackening the entire core with graphite did not improve matters. Core washes of many kinds were then used with the idea of making the skin of the core gas tight, so the gas would be forced out at the ends where vents had been provided. None of these had any effect whatever toward reducing the percentage of scrap until one of plaster of Paris was tried. This plaster of Paris coating stopped most of the porosity, but not all of it. Acetic acid was then added to the plaster of Paris to delay setting but the whole was a very unsatisfactory procedure.

* Asst. Metallurgist, Federal Mogul Corporation.

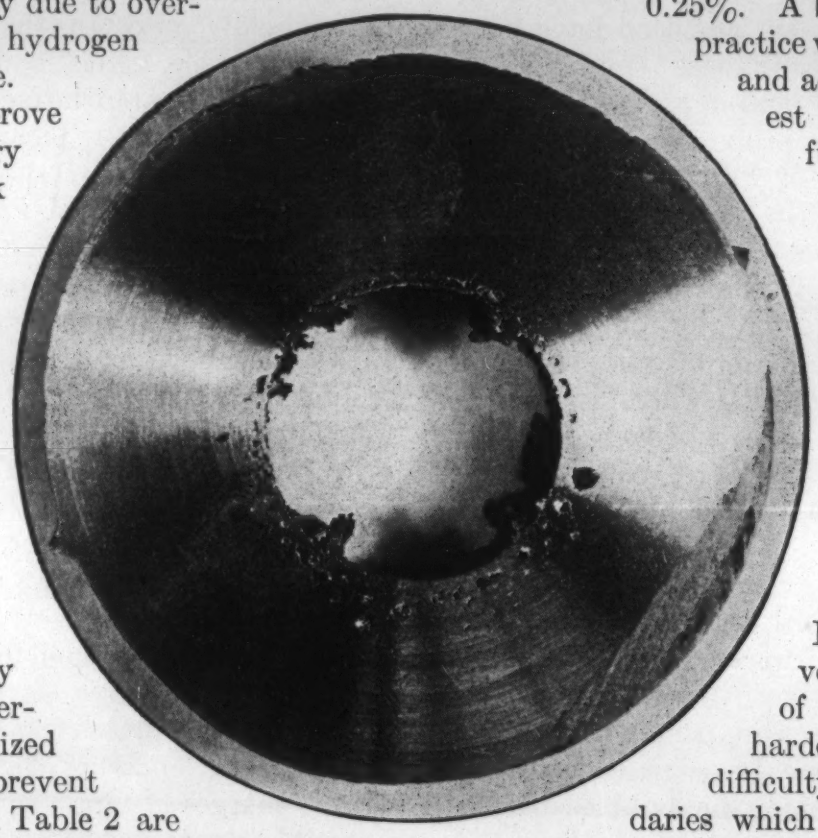
As stated above, these holes when present at all were under the skin of metal adjacent to the core and only occasionally next to the molding sand. Therefore, where possible, green sand cores were tried in order to have the same sand surface on both the inside and outside of the casting. The porosity was stopped entirely in castings so cored. But while the use of small cores coated with plaster of Paris and large cores made of green sand would stop most of the porosity, such a procedure would not be practical on a conveyor system with heavy production.

In the above experiments both new and secondary metals were employed together with four types of furnaces, but no relation could be established between the porosity and any of these variables. Attention was then centered on chemical analyses and after a number were made, it became apparent that the porous phosphor bronze castings contained very small amounts of phosphorus, or none at all, and that in other bronzes usually containing small amounts of zinc, the defectives were practically free of that element. It was then a question if the presence of zinc or phosphorus prevented porosity by making gas less soluble. Accordingly three charges of virgin metal were melted in coke-fired crucible furnaces under heavy charcoal coverings. One was poured without additions of any kind, one with the addition of a small amount of phosphor copper and the other with about 1% zinc. All castings were sound, and after repeating the experiment with the same results, it was concluded that the absence of zinc or phosphorus was not the sole cause of the porosity. The evidence presented by the chemical analyses, however, pointed strongly to the absence of these elements as being at least a contributory factor, and as zinc and phosphorus are both strong reducing agents the effect of oxygen was next considered.

A charge of virgin metals, made up to the composition 80% copper, 10% tin and 10% lead, was melted without covering in an oil-fired revolving type furnace. This type of furnace was selected because of the ease with which its atmosphere may be controlled. During the melting operation the atmosphere was held as nearly neutral as possible, judging from the exhaust gases and the appearance of the metal surface, until just before pouring when a strongly oxidizing flame was thrown over the melt for about ten minutes. The first mold was poured with the metal just as it came from the furnace without additions of any kind. The second mold was poured of the same metal to which was added 0.1% phosphorus in the form of phosphor copper. The first mold or oxidized metal had the ring of holes around the cores. The second mold or phosphorized metal was sound in every respect except for a discolored spot or

two. An analysis of the second showed no phosphorus, it having all been consumed by the over-oxidized condition of the metal. Later heats with both phosphorus and zinc in sufficient quantities to completely deoxidize the metal, gave entirely satisfactory castings. One charge of defective castings made from the oxidized metal was melted in a gas-fired furnace with a reducing atmosphere and with the metal left uncovered to permit the reducing gases to react with the melt. The castings poured had the ring of holes at the core. Another heat melted under the same conditions, except that it was kept in the reducing atmosphere of the furnace for three hours after melting, gave castings free from the ring of holes around the core, but porous all through the metal. This was undoubtedly due to over-reduction and absorption of hydrogen from the furnace atmosphere.

These results seemed to prove that oxidation was the primary cause of the difficulty. Check heats of oxidized metal and metal containing phosphorus or zinc were made and poured into molds containing cores of several kinds. In all cases the results were as expected and the character of dry core material was without influence. Table 1 is a record of these results.



With the conditions of the metal that caused this porosity known it was necessary to determine how the metal was oxidized in the beginning and how to prevent such action taking place. In Table 2 are given the approximate specific gravities of some high lead alloys and lead oxides. It will be seen that with the specific gravity of lead oxide so near to that of the bronze, once it is under the surface of the molten metal it has little chance of floating to the top. Should the surface of the molten metal come in contact with air, conditions are such that most of the oxides formed will be held in suspension. Copper being the major constituent in these alloys probably forms the greatest amount of oxide. This is quickly reduced by lead to lead oxide which because of its gravity is retained within the melt. Tin is the only element present whose oxide when formed may be skimmed off the surface of the melt. If sufficient time were allowed and no more oxide formed, it is possible that tin would reduce the lead oxide, but on an exposed surface the oxides are formed much faster than tin can reduce them, due to its position next to lead in the electromotive series. The consequence is that metal of this composition is in constant danger of absorbing oxygen and once it is absorbed there is little chance of its getting out. It is necessary then to produce and pour metal that is practically free from oxide. This can be done in several ways.

Zinc and phosphorus are both reducing agents, but in some specifications zinc is an impurity. Its use therefore must be accurately controlled, and in many cases for specificational reasons it is impossible to use a sufficient quantity for desired results. Although its action is vigorous it is not sufficiently powerful where oxides are rapidly formed to effect reduction without additions in considerable excess. This is particularly true when an attempt is made to deoxidize in the furnace just before pouring by adding small amounts, say, 0.25%. A better plan is to find out from practice what the furnace loss of zinc is, and add with the charge the largest permissible amount plus the furnace loss. In this way a uniform zinc content may be maintained and castings free from porosity at the core should result.

Phosphorus is an excellent reducing agent but caution must be exercised in its use. Very small amounts greatly change the physical properties of bronze and it is very easy, therefore, to have a harmful excess. From 0.05% up, the effect is very noticeable on the surface of castings as they are much harder to clean, but the greatest difficulty is encountered with secondaries which may contain small amounts of iron. Here hard brittle castings that are difficult to machine will follow if the phosphorus content greatly exceeds the amount mentioned. Additions of less than 0.05% are rarely harmful but do little good unless they represent a distinct excess after reduction of oxides has been accomplished. From a study of furnace results the amount of phosphorus necessary to keep a small excess in the metal at all times is readily determinable, and by so preventing oxidation sound castings with respect to gas around cores should be produced. In the case of new metal charges any reducing agent employed should be used after the copper is melted and before the additions of tin and lead. It is easier to prevent the formation of lead oxide than to remove it after it has been formed.

From the data in Table 1 it may be seen that oxidized metal with the use of dry sand cores produced the porosity described. The same metal poured against green sand cores gave sound castings. Metal com-

Table 1

Condition of Fractured Castings

Metal	1% Oil Core	5% Oil Core	Oil Core Half Baked	Oil Core Molding Sand	Core Dipped in Water	Green Sand Core
80–10–10 oxidized	Porous	Porous	Porous	Porous	Sound[a]	Sound
80–10–10 with 2% P	Sound	Sound	Sound	Sound	Sound[a]	Sound
80–10–10 with 1% Zn	Sound	Sound	Sound	Sound	Sound[a]	Sound

NOTE: "Porous" refers to holes around the core.

[a] Metal sound but molds only half filled.

Table 2

Material		Specific Gravity
Copper 80%, Tin 10%, Lead 10%		9.006
" 74% " 6% " 20%		9.312
" 70.5 " 9.5 " 20%		9.458
" 71% " 9% " 20%		9.25
Lead Oxide	Litharge	9.41
	Powder	9.25
	Red	9.28
	Yellow	9.52
Copper		8.93
Lead		11.34
Tin		7.28

Melting point PbO, 1614° F.

pletely deoxidized by either zinc or phosphorus gave sound castings with all cores. Evidently oxides were not by themselves responsible for the difficulty but had to be in contact with the dry sand core to produce the ring of gas holes.

If oxides formed during melting are lighter than the melt they will in time rise to the surface. This action is in effect a deoxidizing agent and metal so deoxidized should give sound castings. But the alloys here considered contain lead whose oxides are heavy and in most instances retained below the surface. Such alloys are not subject to this mechanical deoxidation and the cores of castings poured with them will come in contact with the included oxides. As lead oxide is very easily reduced, the carbonaceous matter of the cores reacts with it and the products of the reaction are lead and oxides of carbon. The oxides of carbon forming in the freezing metal around the core are entrapped in position causing the ring of holes in the casting.

Foundry difficulties are usually complex in their nature and have their origin confused by effective disguises. Surface indications are seldom safe leads to a solution, and with the difficulty here described cores were unjustly blamed for results from a hidden cause.

◆ ◆ ◆ ◆ ◆

LEADING MANUFACTURERS SECURE LICENSES TO USE "ZINC INSTITUTE SEAL OF QUALITY" TRADE-MARK

Galvanized sheets of certified quality, carrying a zinc coating much heavier than on the average commercial sheet, are now readily available to the consumer through completion of license agreements for the "Seal of Quality" trade-mark of the American Zinc Institute.

The manufacturers who have been licensed to use this "Seal" upon galvanized sheets are the following:

American Sheet and Tin Plate Company, Pittsburgh, Pa.
Continental Steel Corporation, Kokomo, Ind.
The Reeves Manufacturing Company, Dover, Ohio
The Youngstown Sheet and Tube Company, Youngstown, Ohio

The matter is under consideration by other manufacturers of galvanized sheets, and a number of them, including Apollo Steel Company, Apollo, Pa., Bethlehem Steel Company, Bethlehem, Pa., Granite City Steel Company, Granite City, Ill., and Newport Rolling Mill Company, Newport, Ky., have indicated definitely that they are in sympathy with the movement, formal completion of the license agreement being delayed by absence of some of their officials.

The "Zinc Institute Seal of Quality" has been adopted as an emblem for heavily coated galvanized sheets for use as building material, as an aid to the buyer in securing long service and durability. The need of such a guide to quality has been emphasized by recent field investigations of the Institute. These have shown not only a great variation in the zinc coatings on galvanized sheets installed at different times, but also a lack of knowledge of this entire subject on the part of consumers, dealers and even distributors of such sheets.

◆ ◆ ◆ ◆ ◆

RECOVERY OF METALS FROM SECONDARY SOURCES IN 1930

The value of certain nonferrous metals recovered from secondary sources in 1930 is reported to the United States Bureau of Mines, Department of Commerce, as $193,255,100, which is $137,773,800 less than in 1929, and the total quantity decreased 24%. This decrease in value was partly due to the lower yearly average prices of copper, lead, zinc, tin and antimony in 1930. There were, moreover, large decreases in the quantity of each of the secondary metals recovered.

The shipments of scrap copper and brass to Europe declined and the imports were less in 1930 than in 1929. The smelters that treat mainly primary material produced 26,809 tons less secondary copper in 1930 than in 1929.

There was a decrease of 26% in secondary lead reported by regular smelters that treat mainly ore and bullion, and there was also a large decrease in the output of lead in alloys reported by smelters that treat scrap and drosses.

The zinc recovered by redistillation decreased about 12,500 tons, and that recovered by remelting and sweating decreased about 3600 tons. There were also decreases in the quantities of zinc dust, zinc chloride and zinc sulphate made from zinc residues and zinc dross.

The detinning plants treated about 13,400 long tons less clean tin-plate clippings in 1930 than in 1929, and the yield per ton increased considerably. About 69% of the recoveries at detinning plants was as tin content in tin tetrachloride, tin oxide and other chemical compounds, compared with 76% in 1929. The only old tin coated containers treated were those used to make window weights and for the precipitation of copper from mine waters; no tin was recovered in these processes.

The turnover of scrap metals and drosses was below normal for plants using metals operated on a much reduced scale. The constantly declining average monthly prices of nearly all metals made the year unprofitable for secondary metal dealers and smelters. There were few business failures among the large operators, and scrap metals were purchased with caution so that holders of secondary metals hope to profit from future advances in prices.

◆ ◆ ◆ ◆ ◆

New President for Midvale

On August 27th Dr. Harry L. Frevert was elected to the presidency of the Midvale Co., Nicetown, Pa., to succeed the late Alva C. Dinkey. Dr. Frevert became associated with the organization in 1909 when he served as a chemist in the laboratory of the Midvale Steel Co. Since that time he has risen steadily, occupying many important posts, including chief chemist, superintendent of armor plant, superintendent in charge of metallurgy, general superintendent, and vice president.

He was graduated from Harvard University in 1905 with an A. B. degree, magna cum laude, and three years later received the degree of Doctor of Philosophy from the same institution. He taught chemistry at Harvard for several years before joining the Midvale Steel Company. He is a member of the American Institute of Mining & Metallurgical Engineers, the American Iron & Steel Institute and the Electrochemical Society.

Railway Experiments with Aluminum Paint

The old fashioned "box car red" shade is doomed for extinction as a color for railway refrigerator cars. Recent experiments made in the car shops of the Canadian National Railways show that aluminum paint, applied to the roofs of such cars, is more heat resisting than red. The external temperature of a roof covered with aluminum paint was found to be less.

Further experiments are now being made by the railway, and two new refrigerator cars are being painted entirely with aluminum. Special thermometers in the cars will record the internal temperatures, and a record will be made of the ice consumption as compared with that in cars painted red.

VACUUM CASTING

BY H. T. REEVE*

MELTING and casting of metals in a manner to produce the soundest and purest ingots possible with the least amount of piping is a problem that has proved of great interest.

The method of melting a metal or alloy in vacuum and allowing it to freeze in the crucible prevents atmospheric contamination but has two serious disadvantages. Pipes of relatively large dimensions are formed in the interior of the ingots and in the case of alloys, segregations may occur due to the slow cooling.

For the melting and casting in vacuum of quantities of precious metals, such as platinum, up to about 600 grams, we believe the apparatus shown in the sketch to be a quite simple and efficient. A larger unit of the same type, capable of handling at least five times this quantity of metal, is in course of construction.

The source of the energy is the 35 kva. Ajax-Northrup high frequency generator which is too well known to need any description. The inductor coil is mounted on an asbestos board base capable of being tilted through a little over 90°.

Referring to the diagram, a quartz tube A fitting just inside the coil J is used for the melting chamber. This tube is open at the bottom and the end is ground off square so as to form a tight joint with a large rubber stopper P. The top of the tube is closed with a transparent polished quartz plate sealed on, which allows a clear view of the melting and pouring operations. The side arm is sealed onto the upright tube at right angles and is of the same diameter as the vertical tube. The open end of the side arm is ground off square to make an air-tight joint to another rubber stopper H which is held on by atmospheric pressure. Opposite to the side arm junction a small quartz projection D is sealed inside the tube to act as a stop when raising the crucible to the pouring position. There are two connections through the bottom stopper, one, a glass tube Q to the vacuum pump and the other, a metal rod R to push the crucible from the melting to the pouring position. This metal rod is forced up and down by a small hand wheel and gear. The rod is, of course, a tight fit through the stopper and the latter is therefore held down by a metal ring S in order to prevent the whole apparatus being raised (and the quartz side arm possibly broken) by the pressure needed to force the metal rod through the stopper.

To make a casting, the crucible and charge are placed on top of an alundum or quartz tube N, which serves as a pedestal and the quartz tube placed over them. A heated mold E is then introduced in the side arm, a close fitting piece of asbestos board F placed after it as a heat insulator and then a short length of refractory tubing G to act as a spacer between the asbestos board and the stopper. The pump is started and the rubber stopper held against the end of the side arm until the vacuum inside causes the atmospheric pressure to hold the stopper tightly.

When the gage indicates a good vacuum (about $^1/_{10}$ to $^1/_{100}$ mm.), the metal is melted in a few minutes and the crucible raised to the pouring position with the current still on. The whole apparatus is then tilted over by the aid of the hinge T and the metal runs into the the mold and solidifies immediately. As soon as the cast has cooled sufficiently, the pump is stopped, the apparatus let down to air by means of a stopcock and the side arm stopper will then come off, allowing the mold to be removed by again tilting the apparatus slightly. The quartz tube can then be lifted off and the crucible removed. The whole operation in the case of platinum or its alloys can be easily completed in half an hour, while lower melting metals such as nickel or copper alloys will take less time.

The type of crucible used, of course, depends on the nature of the metal or alloy being melted. For many purposes we have found that alundum extraction thimbles made by Norton Company are very satisfactory when fired in an oxidizing atmosphere to as high a temperature as possible.

These are set in a larger quartz or alundum crucible and the space between filled with R. R. alundum; this insulation is held in on top with a thin layer of alundum cement.

WHILE the process of melting and casting in a vacuum is so far primarily a laboratory procedure for use in special research work, Rohn, in Germany, has been applying it in rather large scale practice to the commercial preparation of nickel chromium alloys. When the true effect of "gases in metals" is more thoroughly understood, it is not at all impossible that commercial use of such processes in tonnage production may be found advisable. In the meantime, it is desirable that our metallurgical laboratories study vacuum melting and pouring, not only in making alloys that can only be so handled, but also on those for which the value of such refinements is not yet established. This description of a suitable apparatus should facilitate such work in other laboratories.

For certain alloys we have found it necessary to use zirconia obtained in the electrically fused condition from the Titanium Alloy Mfg. Company. This is ground up to 100–200 mesh in a ball mill, heated with hydrochloric acid to remove iron, washed with water, dried and fired in oxygen to remove any traces of carbon.

This zirconia powder is tamped dry into a quartz or alundum crucible K with a tapered platinum crucible acting as a core. A cushion of low ash filter paper is wrapped around the platinum crucible to allow for shrinkage in the firing. The platinum crucible is brought up to about 1700° C. in the high frequency furnace, when the layer of zirconia next to it will sinter together, forming a crucible M. The outer unsintered portions of the zirconia act as insulation material L. The filter paper burns away and thus allows the platinum crucible to be easily withdrawn.

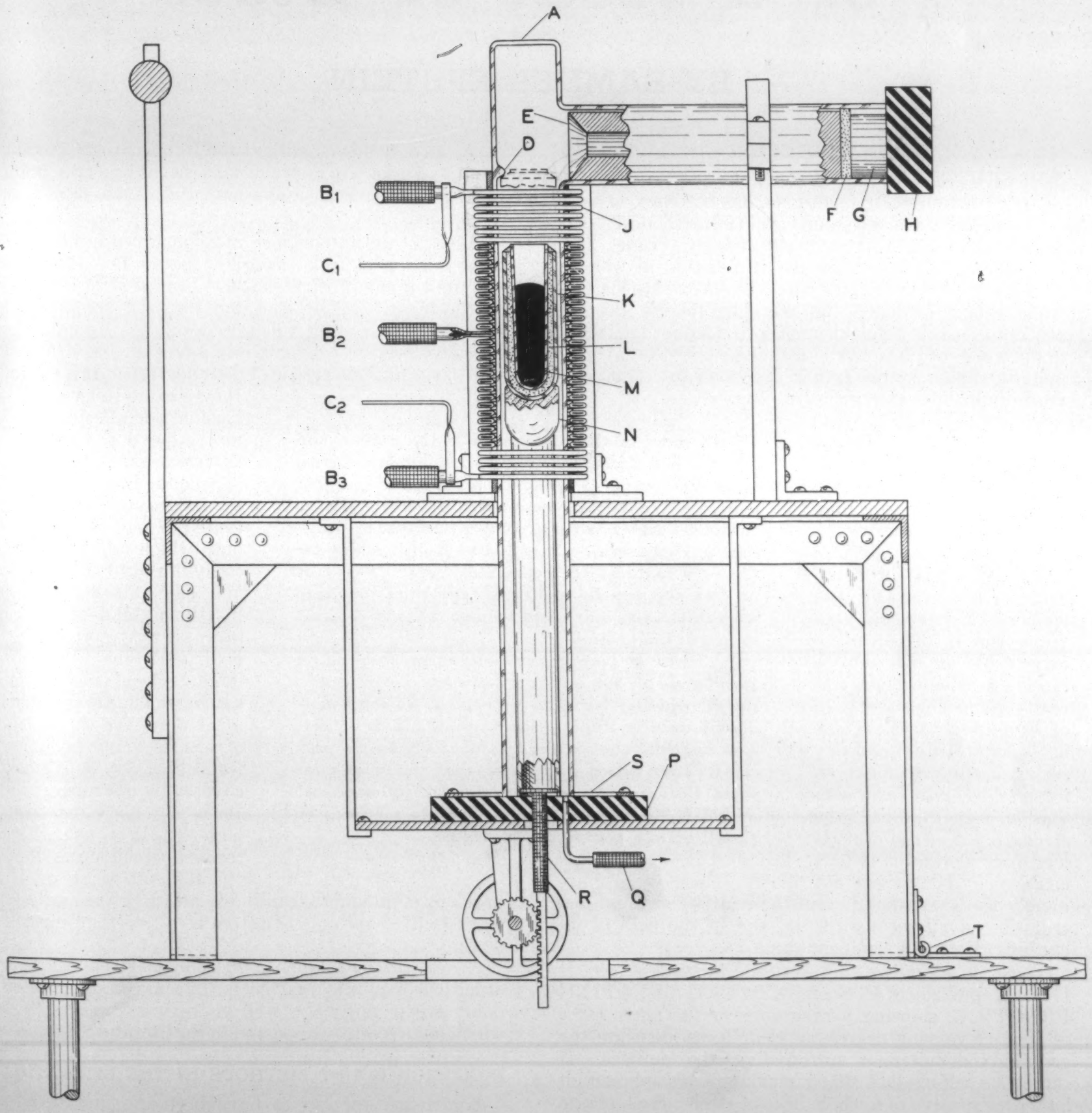
Other metals such as tungsten could be used instead of platinum but the firing would then have to be done in hydrogen or vacuum. Carbon can also be used, but a certain amount of zirconium carbide is then formed and

* Bell Telephone Laboratories, Inc.

the crucible will be gray colored and contaminate the melt with carbon. Once the powder is prepared, the operation of making a zirconia crucible need not take more than half an hour.

The mold can be made of graphite or metal depending on the nature of the material to be cast. It may be of interest to some to know that nickel, for instance, although melting at 1450° C., can be used with perfect safety as a mold for the casting of platinum, the pouring temperature of which is about 1800° C.

Vacuum melted ingots $^1/_2''$ diameter and weighing about 500 grams, after cropping off the head, have been repeatedly drawn to 0.003″ in one continuous length of wire without breakage. This is one of the best proofs that vacuum cast ingots are sound and free from cavities.



LEGEND

A—Quartz tube with transparent top.
B1, B3—Water outlets.
B2—Water inlet.
C1, C2—High frequency current leads.
D—Crucible stop.
E—Mold.
F—Asbestos board.
G—Refractory tube for spacer.
H—Rubber stopper.
J —High frequency coil.
K—Outer crucible.
L—Refractory insulation.
M—Inner crucible.
N—Support for crucible.
P—Rubber base.
Q—Connection to vacuum pump.
R—Metal rod through stopper.
S—Metal ring for holding down stopper.
T—Hinge for tilting apparatus.

A Suggested Method of Determining the Cleanness of a Heat of Steel

BY SAMUEL EPSTEIN*

INTRODUCTION

IN SEVERAL grades of steel, cleanness, or freedom from non-metallic inclusions, has become one of the main criteria of acceptance, yet the methods in vogue for determining this are surprisingly crude. The accountant duly recording the transaction in which a heat is accepted or rejected would be shocked to learn on what shaky evidence the metallographer's decision was made. It is a rare chemist who does not realize the importance of adequate sampling, but the average metallographer seems rather oblivious to it, at least when considering inclusions and judging from current standards and specifications.

Indeed the metallographer will have only himself to blame if the chemical methods which are now being developed for determining the cleanness of steel should largely supplant the microscopic—regrettable as this would be, for the microscope, correctly used, has certain evident advantages. There is nothing like actually seeing a thing to make an impression or to carry conviction. In general, the strong point of the metallographic method is that it enables us to determine not merely the amount, but also the relative size and distribution of microconstituents, and in the field of inclusions this is of preëminent value.

The accompanying "non-metallic inclusions" charts (Fig. 1) published in Sherry's STEEL TREATING PRACTICE, showing micrographs of the appearance of steel of varying degrees of cleanliness illustrate the general indefiniteness surrounding the subject. It should be self-evident that a single micrograph cannot be representative of a whole heat of steel. Such charts leave too much to the judgment of the metallographer, who needs more precise guides on which to base his decision. The usual specification in respect to cleanliness is also extremely vague.

Another example of a chart, equally unsatisfactory, stated to be used in a Swedish steel plant, is shown in Fig. 2, taken from the book by Benedicks and Löfquist, NON-METALLIC INCLUSIONS IN IRON AND STEEL.

THE proof of the pudding is in the eating, and the real decision as to whether a heat of steel is of the proper cleanliness for a given purpose should ultimately be based on direct evidence as to the behavior of steel of different degrees of cleanness in that service. It would be foolish to pay for the care required to secure cleanness that is not needed, and equally foolish to fail to use that care where cleanness may avoid failures that could result in loss of life or limb.

But until we can evaluate cleanness, there is no good way to start collecting such information. Hence, whether for a given purpose, we shall ultimately need to impose cleanness standards or not, it is essential that a measure of cleanness be provided. Even those who think that for most purposes the urge for cleaner steel is unnecessary, should be in favor of finding definite methods of quantitatively comparing cleanness.

As an outcome of work at the Illinois Steel Company, South Works, to improve this situation, two points, which really merge into each other, seem worth emphasizing.

First, is the importance of adequate sampling from a heat of steel, i. e., samples should be taken from different ingots in the heat and from different portions of the ingot. Likewise, a definite sized bar should be examined, indicating a definite reduction from ingot to bar, and likewise a definite relation of the bar size to the size of the finished article of manufacture. It is obvious that size and shape of inclusions are affected by the method and the degree of deformation.

Second, is the division of inclusions into two classes—the very small ones which are generally fairly uniformly distributed and can thus be handled by the usual technique of choosing a representative field, and the occasional large inclusions and segregates which are scattered at random, and the amount of which cannot be judged from the very small field covered by one micrograph. It is these occasional larger inclusions and segregates which constitute the difficult part of the problem of judging cleanliness, and it is primarily for these that a more quantitative count method must be used.

A description of such a method is given below, in order to open the matter for discussion, but before doing so, it might be well to review three methods which have recently appeared in the literature.

INCLUSION COUNT METHODS IN THE LITERATURE

Kjerrman[1] appears to have been the first to have published a method for carefully measuring and counting the inclusions in steel. He examined definite sized fields with a micrometer ocular, several fields from one specimen, and expressed his results as the number of inclusions per sq. mm., the average size of the inclusions, and the maximum size. He used a magnification of about 200 and counted all the inclusions down to those 0.002 mm. in size. He frequently separated the inclusions into two groups—the silicates and sulphides.

* Metallurgist, Battelle Memorial Institute; formerly Metallographer, Illinois Steel Company.

[1] Hans Kjerrman. An Inclusion Count Method and Some of Its Practical Results. *Jernkontorets Annaler*, Vol. 4, 1929, pages 181–199.

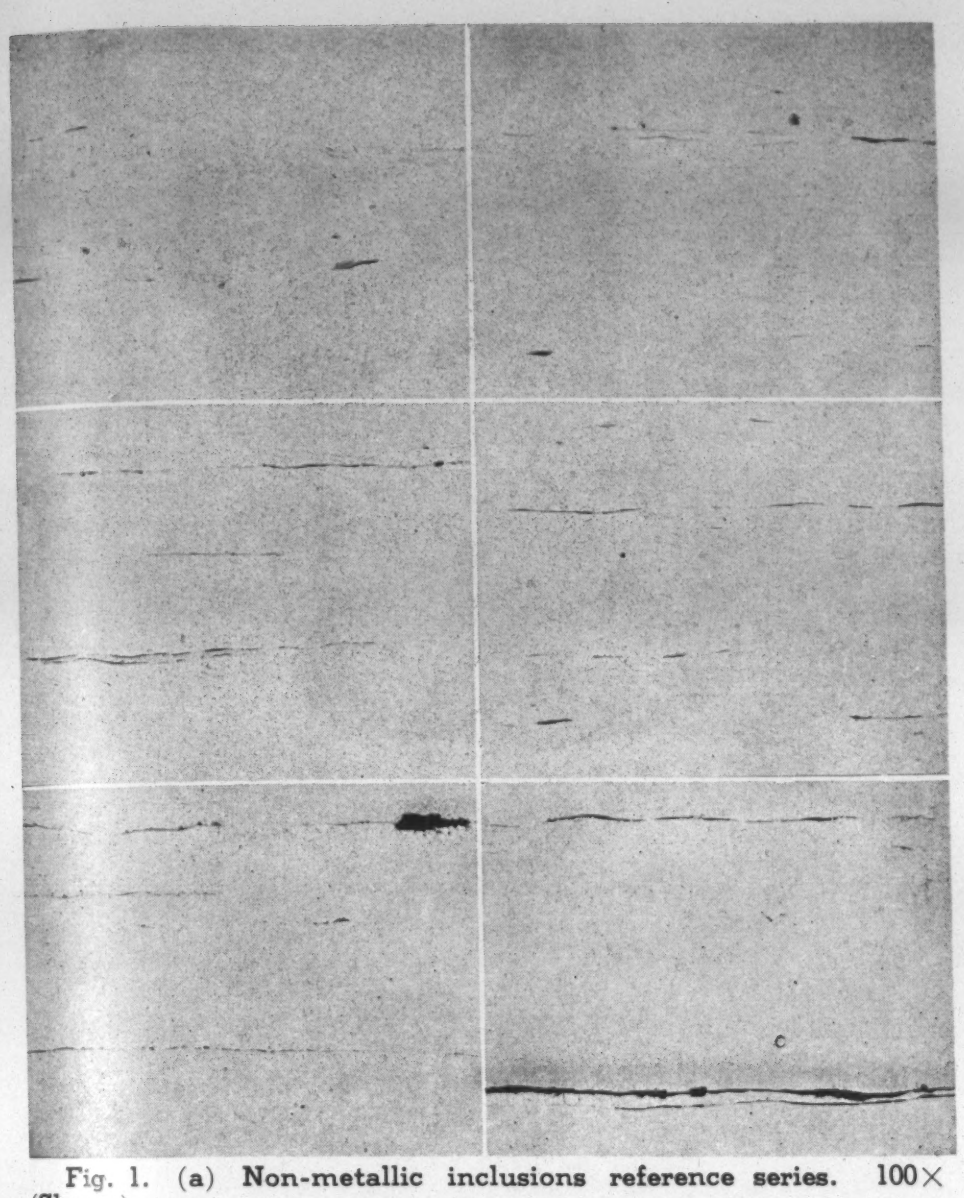


Fig. 1. (a) **Non-metallic inclusions reference series.** 100× (Sherry).

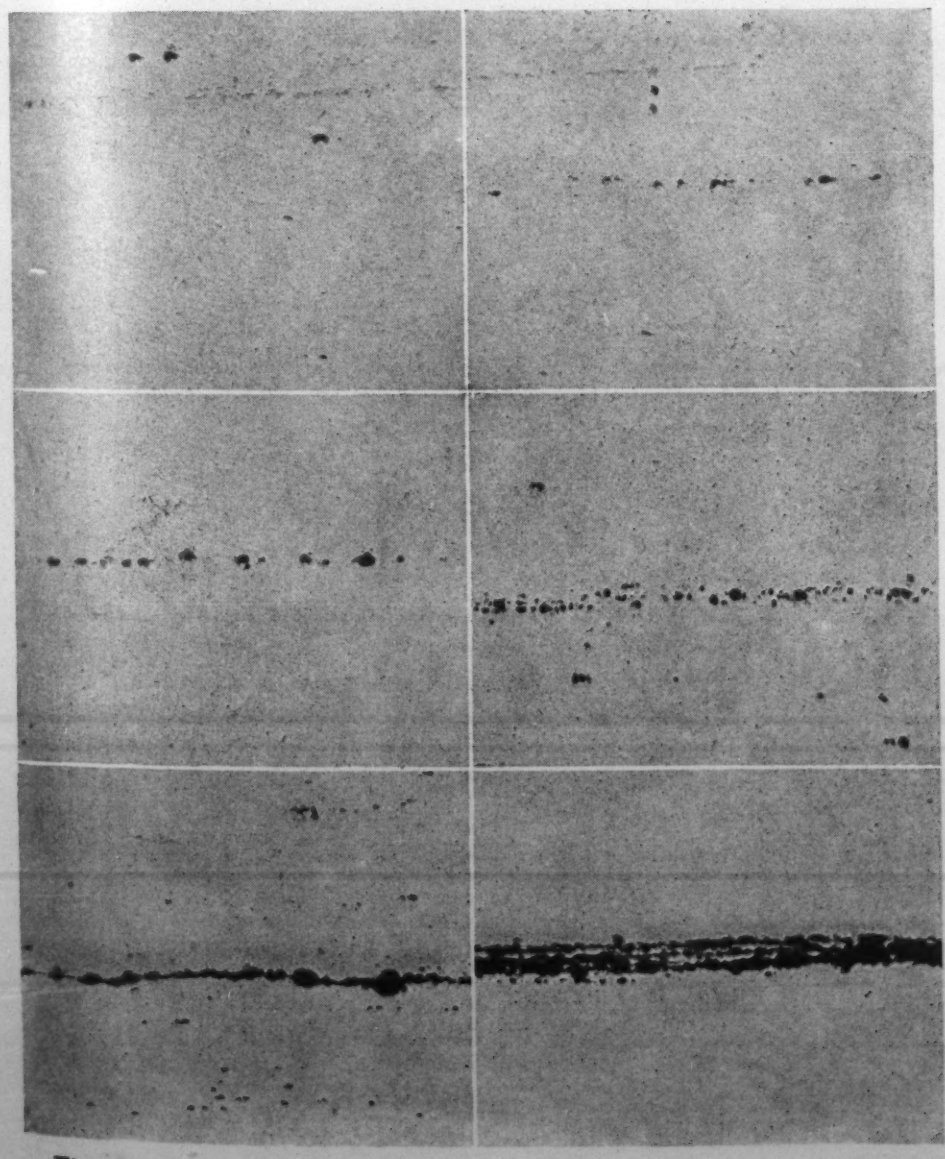


Fig. 1. (b) **Oxide inclusions reference series.** 100×(Sherry).

He noticed that the inclusions appeared smaller as the bars were reduced to smaller sizes in rolling and, therefore, used longitudinal sections of the same size bar, 7/8" square, in all of his work. His specimens were taken from the middle of the middle ingot of the heat.

Kjerrman's method is satisfactory for the small inclusions, and he was able to get fairly good correlation between different samples from a heat in the number of inclusions per sq. mm. and in the average size of the inclusions, but he states, "However, the maximum sizes for the different inclusions showed a relatively poor relation for parallel samples." The principal weakness of Kjerrman's method would seem to be that his samples were not spread sufficiently over the heat, and that he did not survey large enough portions of his samples to get an accurate measure of the amount of the large occasional inclusions.

Herty[2] was interested in the amount of non-metallic inclusions in small ladle test samples of experimental melts and did not extend his method to the rolled material from large commercial heats. He used a micrometer ocular at 250 magnification and surveyed thin strips of a given area of the section through the casting from the center to the outer edge, for inclusions, segregating them into various sizes according to their diameter, and then calculated the weight percent of non-metallic matter. In the small ladle test ingots the inclusions are very small; evidently all that were resolved at the magnification used were counted.

It should be noted that even here where an absolute value of the weight percent of non-metallic matter was desired, the area of each individual inclusion was not measured very closely, but they were divided into several groups according to their diameters. This segregation into groups is a characteristic of all the inclusion count methods, as it would be unnecessarily time-consuming to measure each individual inclusion accurately. A valuable innovation in Herty's method is that he completely surveyed certain sized strips of the polished specimen, instead of

[2] C. H. Herty, Jr., C. F. Christopher & R. W. Stewart. The Physical Chemistry of Steel Making: Deoxidation with Silicon in the Basic Open Hearth Process. *Coöperative Bulletin* No. 38, *Bureau of Mines & Bureau of Metallurgical Research, Carnegie Institute of Technology*, 1930, pages 25–29.

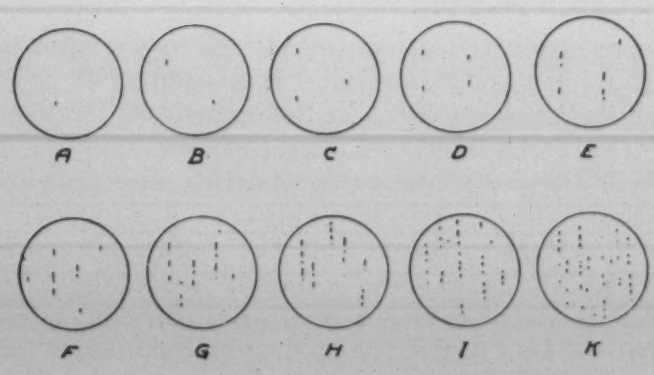


Fig. 2. Example of Standard Scale for Amount Inclusions (Benedicks and Löfquist).

examining only one or more fields of view in the ocular of the microscope.

Kinzel and Crafts[3] have made the most comprehensive recent study of the effect of inclusions on the static and dynamic properties of steel. They stated that "the present commercial rating of inclusions is unreliable." In the method they devised they photographed a number of representative fields of longitudinal sections of 2″ round and square bars at 50 magnification. The negatives were then enlarged by projection and the length of the inclusions measured. They counted all inclusions down to a size of 0.005 mm. and expressed their results as the number of inclusions of a given size per sq. mm. and as a "total length figure," i. e., the sum of the lengths of all of the inclusions per sq. mm., as if they were placed end to end.

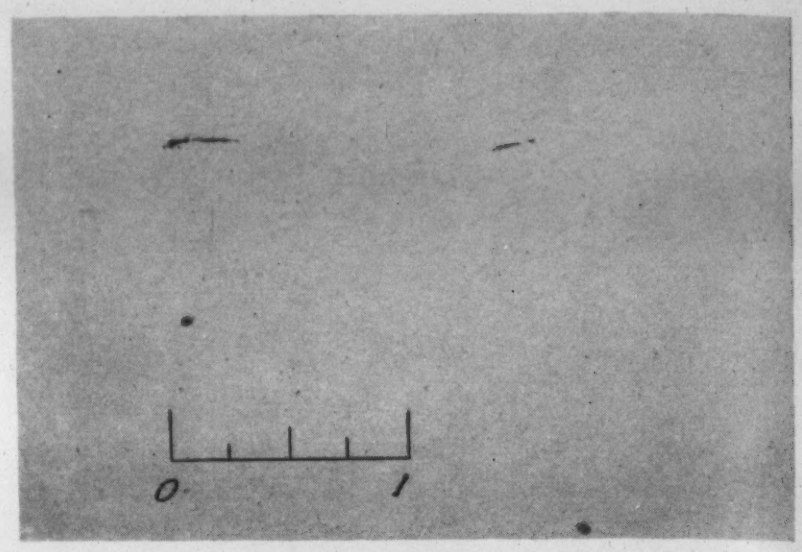


Fig. 3. "Small" Inclusion. Weight 0.

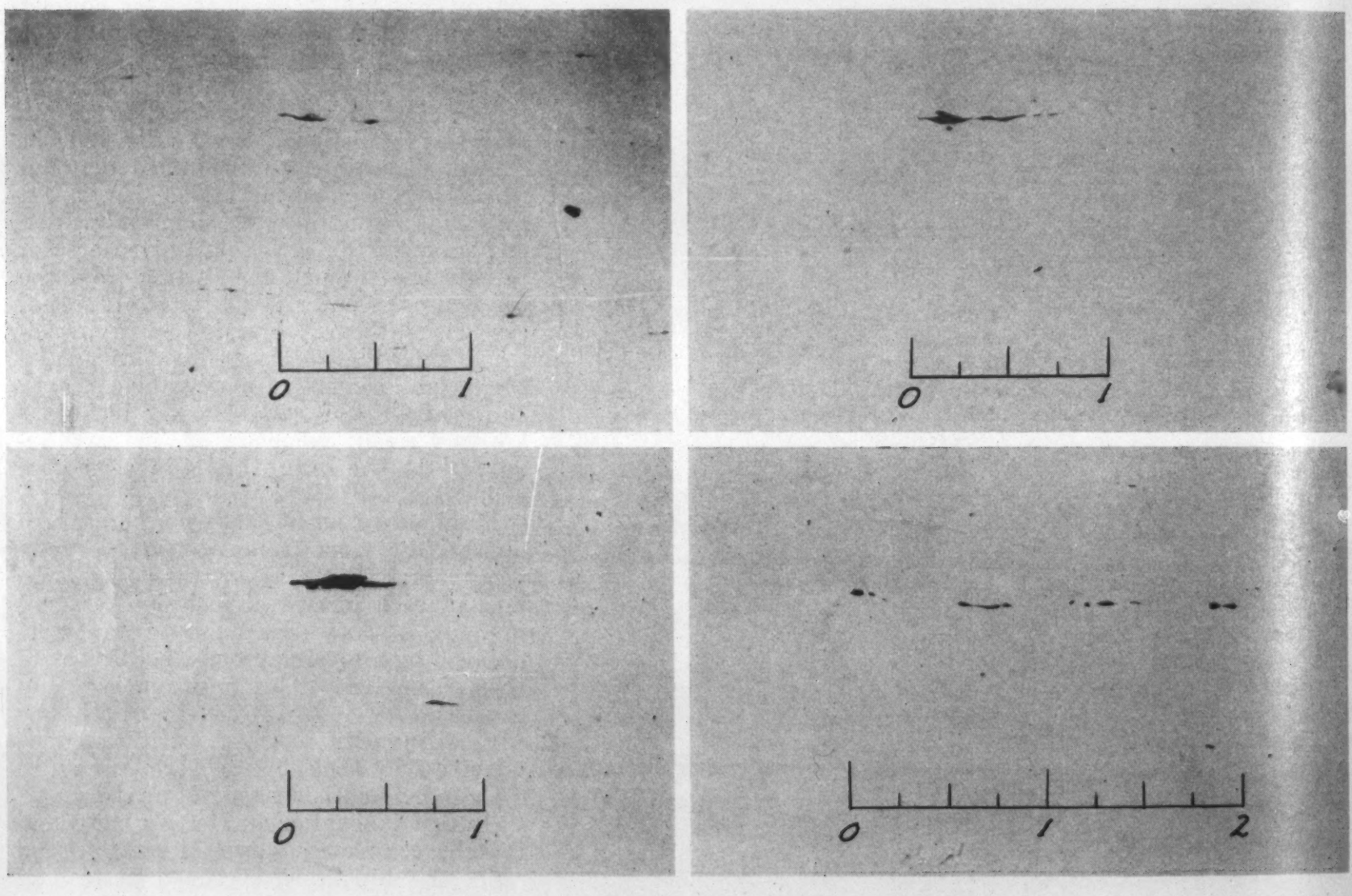


Fig. 4. Examples of "Medium" Inclusions. Weight 1.

The difficulty, as these authors stated, in thus expressing the results is that the number of inclusions depends largely on the minimum size counted, whereas the total length is affected mainly by the length of the larger inclusions, and as comparatively small fields were observed, the errors in this factor due to sampling might be considerable. Apparently no weight was given to the thickness of the inclusions. Since they were concerned with correlating the cleanness of certain bars with their mechanical properties, the problem of adequate sampling of a heat did not enter in their work.

The authors found that "by means of chemical analysis for inclusions and vacuum fusion determination of oxygen, large erratic deviations in impact strength which are not due to visible inclusions have been found to be associated with non-metallics, which are too small to be seen in the microscope or to collect on filter paper." Although further proof of this statement would seem to be required, the point here for our purposes may well be that the microscope is most useful for an examination of the larger inclusions; the extremely small ones, submicroscopic or visible, can probably best be gaged by the methods suggested above, and by their effects on the mechanical properties.

[3] A. B. Kinzel & W. Crafts. Inclusions and Their Effect on Impact Strength of Steel. *Technical Publication* No. 402, *American Institute of Mining & Metallurgical Engineers*, February 1931.

PROPOSED METHOD

This method was developed independently of those described above, at the South Chicago plant of the Illinois Steel Company. The first consideration was that of adequate sampling. It was evident that systematic sampling from stated positions of the ingot and from stated ingots in the heat was much superior to

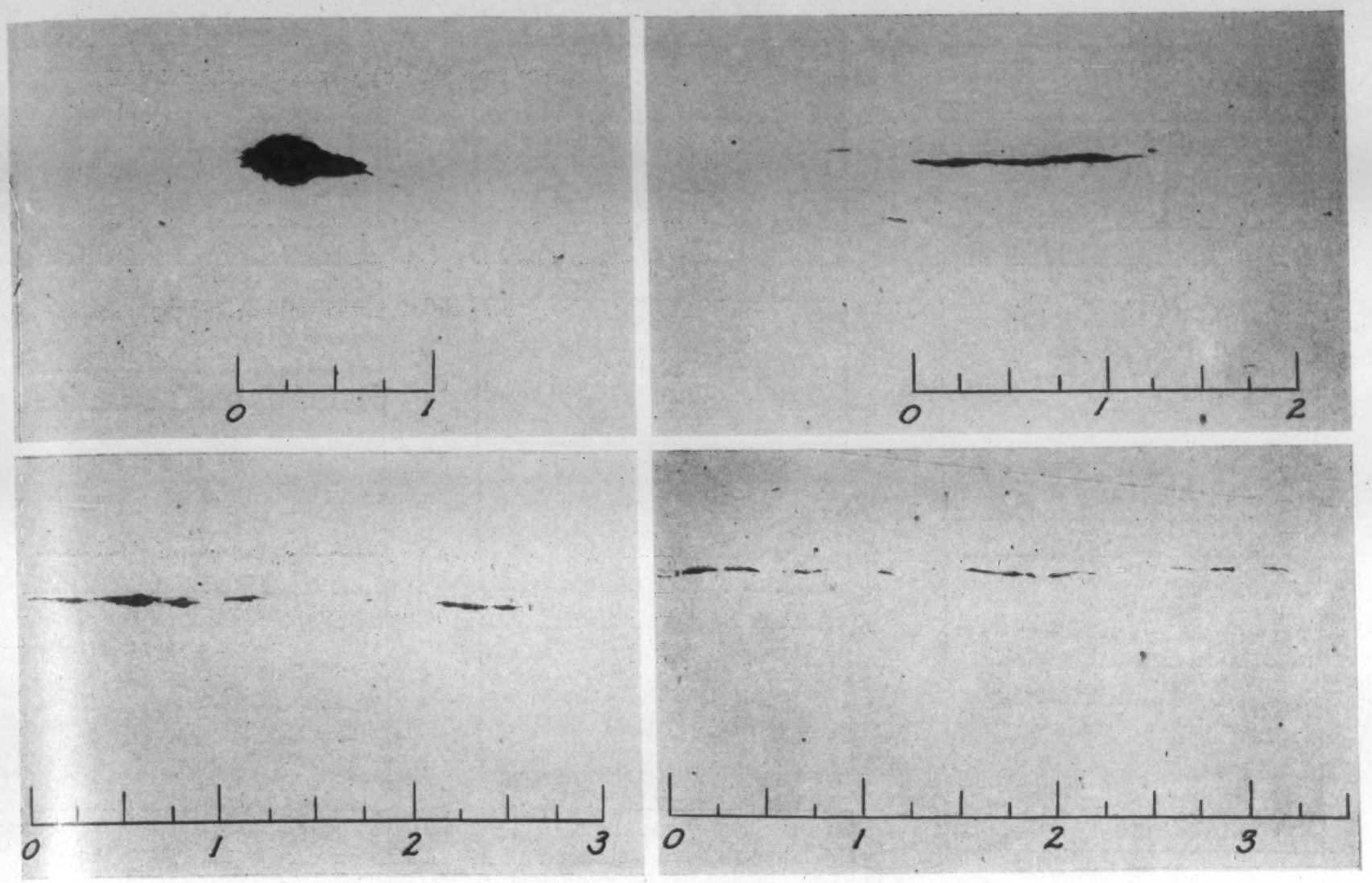


Fig. 5. Examples of "Large" Inclusions. Weight 2.

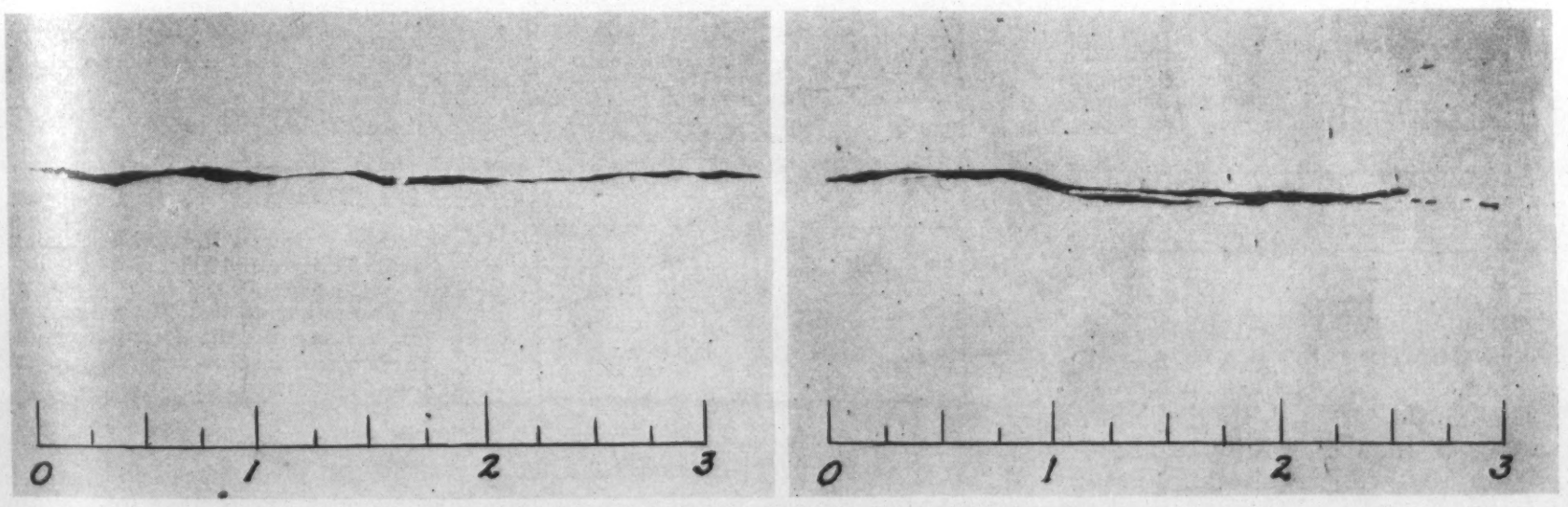


Fig. 6. Examples of "Double Large" Inclusions. Weight 4.

random sampling. The minimum number of samples taken from a heat was nine, these being from the top, middle and bottom billets, of the first, middle and last ingots, although frequently four ingots and sometimes four billets from each ingot were examined. The specimens were longitudinal sections through the center of 2″ round bars.

In the basic electric furnace steel which was studied, the general background was very clean, few sulphide inclusions being present, owing to the low sulphur content of about 0.010%. However, occasional large silicate and oxide inclusions and some segregates of sulphide and other inclusions were encountered. The method of attack for determining the relative amounts of these larger inclusions, therefore, was not

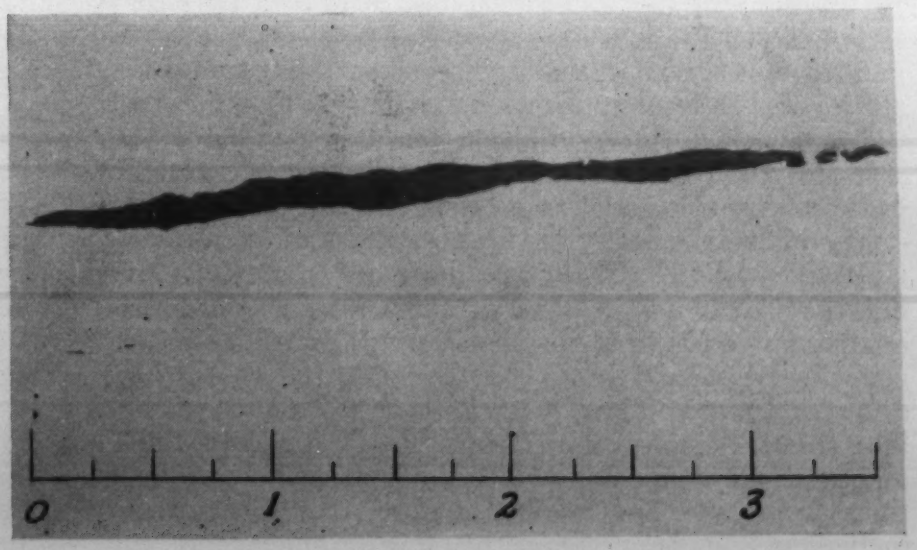


Fig. 7. Examples of "Triple Large" Inclusion. Weight 6.

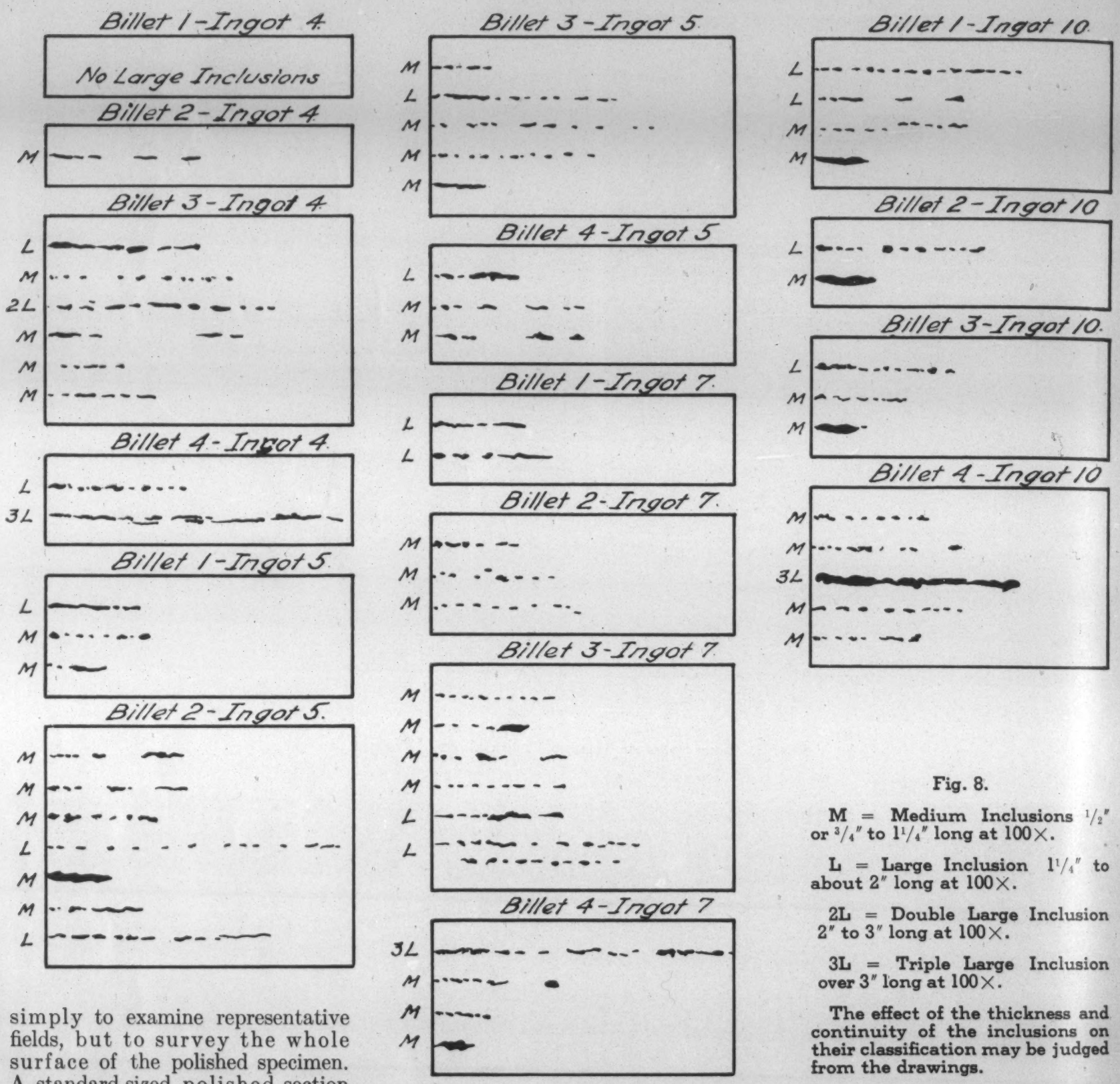


Fig. 8.

M = Medium Inclusions $1/2''$ or $3/4''$ to $1\,1/4''$ long at 100×.

L = Large Inclusion $1\,1/4''$ to about $2''$ long at 100×.

2L = Double Large Inclusion $2''$ to $3''$ long at 100×.

3L = Triple Large Inclusion over $3''$ long at 100×.

The effect of the thickness and continuity of the inclusions on their classification may be judged from the drawings.

simply to examine representative fields, but to survey the whole surface of the polished specimen. A standard sized polished section was used, this being a longitudinal section, $1/2$ square inch in area, through the axis of the $2''$ round extending $1/2''$ along the length of the bar, and from the center to the outer surface. In the earlier work an attempt was made to photograph the inclusions, but later this was eliminated, and the inclusions were simply measured with a micrometer ocular and recorded as the sample was surveyed. The magnification used was 100 diameters.

In expressing the results an attempt was made not to lose the qualitative value of the ordinary microscopic examination in which the relative size and distribution of the inclusions are judged, and still to adopt a quantitative method. This was done by weighting the different sizes and shapes of inclusions which is, of course, not easy to do, since it must depend on preconceived notions as to the damaging effects of the different types. Thus, there is the question whether a long thin inclusion is more damaging than a short thick one, and whether a long continuous inclusion is worse than an equally long segregate of small discontinuous inclusions. It is not always the effect on the mechanical properties that is important. For example, in ball bearing steel a large inclusion at the surface may show up as a rough spot after grinding and cause the bearing to be rejected during inspection. However, the difficulty of weighting the inclusions can be overcome fairly easily and should readily be adjustable by agreement.

The inclusions were classified into five groups—small, medium, large, double large and triple large, the "weights" given to these being 0, 1, 2, 4 and 6, respectively. Figs. 3, 4, 5, 6 and 7 show micrographs illustrating the sizes of the types given the different "weights." The scale on the micrographs is in inches, and the magnification is 100×. It will be observed that thin inclusions less than $0.005''$ in length were not counted.

No attempt was made to express the results in terms of absolute values, such as the area or number of inclusions per unit area. Instead, a simple number was assigned to each specimen, this being derived by adding the "weights" of all the inclusions found. The sum of these numbers from all of the specimens of a heat

divided by the number of specimens was then used as the "index number of cleanliness of the heat."

It should be understood, of course, that in comparing the index numbers of different heats the same procedure should be followed in all. In setting up standards, different ones should be used, depending on the size of the finished bar.

It may appear that counting and measuring the inclusions in a section is a very time-consuming task. However, when the very small ones are omitted, as described, a survey of the size section indicated can be made fairly rapidly—in about ten minutes or less.

For purposes of record, it may also prove desirable to represent by a drawing each inclusion as it actually appears under the microscope. This can be very quickly done by the use of square ruled paper with the aid of the micrometer ocular. Fig. 8 illustrates the drawings made of the inclusions in 16 specimens from a heat. The time consumed in drawing is not very great and may be considerably reduced by practice.

Mention must here be made of the notorious fact that the "clean" or "dirty" appearance of a metallographic specimen may depend greatly on the quality of the polish, although polishing technique seems to have improved considerably in recent years. On rare occasions a specimen may be made to look cleaner as a result of faulty polishing, because the inclusions are covered up by smearing. This condition can be detected by etching and repolishing, which procedure is recommended in all doubtful cases. The more usual trouble, however, is the occurrence of "pitting" or the formation of "comet's tails" about the inclusions and speckling or rusting. The former can be overcome by using thin polishing cloths with very little "nap;" the latter, by avoiding too lengthy polishing or insufficient wetting of the polishing wheels and by drying the sample immediately after each polishing stage. It is remarkable how rapidly traces of moisture will attack and pit the surface of a steel specimen. Acid fumes in the atmosphere will further aggravate matters and can be guarded against by the judicious use of a desiccator. A recommended procedure which will give a good quality polish for inclusions is described in the Bureau of Standards Journal of Research, Vol. 3, November 1929, page 783.

RESULTS OBTAINED

Perhaps the best way to judge the accuracy of the results possible by the use of the above method is to determine the variations obtained upon regrinding and repolishing identical specimens. Table 1 shows the results after regrinding and repolishing specimens from two heats.

The averaged results of Table 1 show that there is fairly good correspondence between the separate examinations of the same group of specimens. The average index numbers for one heat are sufficiently different from those of the other to place the two heats in separate grades. Perusal of the table will also indicate that the examination of a single specimen may lead to an erroneous judgment of the heat.

The billets are numbered according to their position in the ingot, billet 1 being from the upper portion and billet 4 from the lower. It will be observed that the specimens from the lower portion of the ingot have higher index numbers, that is, they contain more inclusions (particularly silicates and oxides). This is in agreement with the work of Dickenson and of the committee of the British Iron and Steel Institute on the Heterogeneity of Steel Ingots.

Table 1.

Heat A					Heat B			
		"Index Number of Cleanliness" Polishing					"Index Number of Cleanliness" Polishing	
Ingot Number	Billet Number	First	Second	Third	Ingot Number	Billet Number	First	Second
4	1	3	1	0	4	1	8	2
4	2	0	1	1	4	2	4	8
4	3	7	7	8	4	3	15	15
4	4	5	7	6	4	4	8	17
5	1	3	5	4	5	1	4	10
5	2	2	2	9	5	2	11	11
5	3	3	1	6	5	3	12	12
5	4	9	8	4	5	4	18	13
7	1	3	4	4	6	1	7	6
7	2	3	2	3	6	2	10	5
7	3	9	9	8	6	3	15	11
7	4	7	5	7	6	4	13	10
10	1	3	5	4	7	1	2	2
10	2	1	0	3	7	2	8	7
10	3	1	3	4	7	3	13	10
10	4	9	7	6	7	4	11	14
Average		4.25	4.06	4.87	Average		9.94	9.56

Tables 2 and 3 show the results of averaging the index numbers of specimens taken from the upper and lower portions of ingots of a number of heats.

Table 2.

	Index Number	
Heat Number	Specimens from Upper Portions of Ingots	Specimens from Lower Portions of Ingots
1	10	12
2	6.3	12.9
3	2.6	10
4	2.6	5.9
5	5	12
6	5.4	9.4
7	9	11.2
8	3.5	8.6

Table 3.

		Index Number		
Heat Number	Average	Top	Middle	Bottom
A	20.00	17.33	15.3	28.6
B	25.55	21.00	24.00	31.66
C	19.44	16.33	22.66	20.00
D	7.33	1.00	9.66	13.00
E	32.9	19.00	29.6	50.00
F	31.66	23.33	35.66	36.00
G	24.7	17.66	24.33	32.00
H	30.22	19.00	27.33	44.33
J	6.3	2.66	5.66	7.33
K	17.10	9.00	19.00	20.00
L	11.44	9.00	10.33	15.00
M	8.66	6.00	7.33	16.00
N	20.22	18.00	21.33	23.66
O	12.9	8.66	14.00	16.00
P	7.11	4.33	5.00	13.00
Q	9.90	3.33	8.66	17.66
R	25.66	24.00	24.33	28.66
S	6.77	5.33	6.00	9.00
T	7.44	5.00	8.33	9.00
U	7.44	11.33	6.33	4.66
V	4.66	2.33	4.00	6.00
W	3.66	2.33	4.66	4.00

The consistent differences in index numbers between the upper and lower portions of the ingots give an indication of the reliability of the method used. Again, it may be pointed out that they also indicate that the examination of random specimens from a heat may lead to error.

The method described appears to lend itself readily to setting up standards of acceptance, for different grades of steel. From an analysis of the results obtained in the examination and reëxamination of a number of samples from several heats, it should be possible by statistical methods to decide the number of samples which should be examined from a heat. From an inspection of the results already obtained it would not seem necessary to use an excessive number. Of course, in doubtful cases resort can be had to repeated examinations of the same samples or the examination of additional samples.

Grateful acknowledgment is made to Mr. C. L. Kinney, Jr., Director of the Physical Laboratory of the South Works, Illinois Steel Company, under whose direction the work was done; to Mr. Burks Kinney for efficient aid in the great amount of metallographic work; and to Mr. Charles F. Ramseyer, who suggested drawing the inclusions on graph paper.

POURING PRACTICE for Avoidance of Defects in Aluminum Ingots for Rolling

BY G. L. CRAIG*

DEFECTS that undoubtedly cause some ninety-eight percent of the rejections in the manufacture of sheet aluminum may be listed as follows:

Blisters	Surface Scratches	Brown Stain	Pinched
Dirt Slivers	Rolled in Scratches	Off Gage-Buckles	Off Size
Clean Slivers	Cracks	Holes	Off Temper
Dirt	White Stain	Coil Marks	Pits
	Waves and Buckles		

Blisters and the various types of slivers are by far the most difficult of these to control, and in most instances their origin may be traced directly to some phase of the melting and casting operation.

The term "slivers" refers to the defects which are produced by the elongation of a porous area or of non-metallic inclusions during the rolling process. The occurrence of such defects is more often due to porosity than to inclusions. Non-metallic inclusions in aluminum and aluminum alloys generally originate in the melting furnace, owing to improper fluxing of the melt, thus resulting in particles of aluminum oxide being suspended in the bath and in turn transferred into the crucible on tapping. The greater number of such particles will usually rise to the surface, but in some instances large areas are found in sheet where comparatively small inclusions have been elongated considerably during the rolling process. In present practice in rolling mills the melt is thoroughly cleaned by proper fluxing and skimming, and but little opportunity exists for such particles to find their way into the castings. Hence attention should be focused on porosity.

MELTING AND CASTING

Three types of metal were used: pure remelted virgin aluminum (99.5+% aluminum), pure virgin aluminum plus 40% mill scrap, and secondary aluminum (98.0 to 99.0% aluminum). In addition to these a limited number of experiments were made with an alloy containing 1.15% of manganese, balance aluminum.

All melting was done in a one-ton stationary, gas-fired, open-flame furnace, under works conditions. Details of construction of the furnace employed have been described elsewhere.[1] The charge was added into the preheated furnace operating with a slightly reducing flame. After the charge had reached approximately 1500° F. a mixture of 1 part of cryolite to 2 of ammonium chloride was thrown over the entire surface of the bath, and the whole mass was violently stirred. After stirring, the doors were closed and the bath allowed to remain in contact with the flux for approximately 10 min. The dross formed by the action of the flux was then removed. The temperature of the molten bath was held between 1450° and 1500° F.

The required amount of metal was then tapped into a No. 150 plumbago crucible, skimmed, and taken to the mold line-up for pouring. Temperature measurements were taken periodically, by means of an immersion pyrometer, so that the metal could be poured at the desired temperature.

The crucible was held in a position, so that the lip was just at the edge of the mold cavity, and then tipped up by means of the shank, so that the metal flowed evenly down the side of the mold. When the surface of the metal in the mold had risen to within about 3 inches of the top, the mold was lowered at a constant speed, traversing the arc, as shown in Fig. 1. This uninterrupted flow of metal was continued until the mold had assumed the vertical position and was full. The crucible was then removed and the mold fed at the head with liquid metal from a hand ladle. This operation consumes from 3 to 5 min. and the feeding was continued until the ingot had completely solidified.

Fig. 2 indicates the manner in which the mold is filled by employing various tilting arrangements. By the use of a crucible hooked directly on to the mold and operated through the same lowering mechanism as the mold itself, it would be possible to have a constant flow of metal into the mold. By approaching the curve for a constant flow from the crucible there is less tendency for the formation of cold shuts, which in many cases cause pronounced defects on fabrication. The nature of such a defect will generally be that of a scale sliver, or crack. If the metal is poured too rapidly at a high temperature, resulting in a certain amount of agitation, cold shuts will be formed, with their surfaces covered by minute layers of aluminum oxide. Such areas will fail when subjected to rolling stresses.

Molds of the general design, as shown in Fig. 1, with inside dimensions of $14 \times 24 \times 3\frac{1}{4}$ inches were used exclusively in these tests. In some cases a straight side mold was used, but since the tapered side mold appeared to offer distinct advantages the greater part of the castings was poured in this type of mold.

In practice the angle Θ (Fig. 1), is generally set at approximately 5° by adjusting the stop on the electric hoists used to raise and lower the mold from the vertical to the pouring position. In this series of experiments the angle was varied from 5° to 45°. Varying this angle affects the formation of cold shuts, but does not have any appreciable effect on the percentage of the three defects with which the work described in this paper was concerned. The greater the angle, the greater is the tendency for the metal to be agitated during the pouring process, no matter how slowly or carefully the pouring is executed. Slow pouring of the metal first entering the mold is of utmost importance, regardless of the angle. This speed can be increased to some extent during the drop of the mold, but when the mold is approaching the vertical, the rate should be decreased in order to feed any secondary pipe in the center of the

* Battelle Memorial Institute.

[1] R. J. Anderson. A Small Stationary-Hearth Furnace for Aluminum Melting. *Industrial Gas*, Vol. 9, March 1931, pages 15–17.

billet and thus to reduce the quantity of metal required to fill the final pipe.

The speed at which the metal enters the mold and the total time of pouring varies greatly at different plants. In some cases, a 104 lb. ingot, of the size indicated, is poured in 30 sec., the time of heading excluded. Ingots cast in this manner are generally inferior to those poured at a slower rate, such as three minutes. Increasing the time of pouring permits freezing from the bottom upward, whereas freezing proceeds from the walls of the mold when the time of pouring is short. Since slow pouring prevents undue agitation and allows freezing to progress from the bottom upward in a uniform manner, it is preferred.

Aluminum and aluminum alloy ingots for rolling into sheet are generally produced in chilled cast iron book molds, the shapes and dimensions depending upon the average size of the sheet required. Generally a mold size is chosen which will give the greatest latitude in the production of various shapes, and usually one type of mold, which will be required to produce the greater number of castings, is standardized at a given plant. Special molds, however, are generally available for the production of billets of unusual sizes. Many features of molds deserve detailed consideration, since by studying mold conditions and the characteristics of each individual mold it is often possible to make alterations that will markedly decrease the percentage of defects.

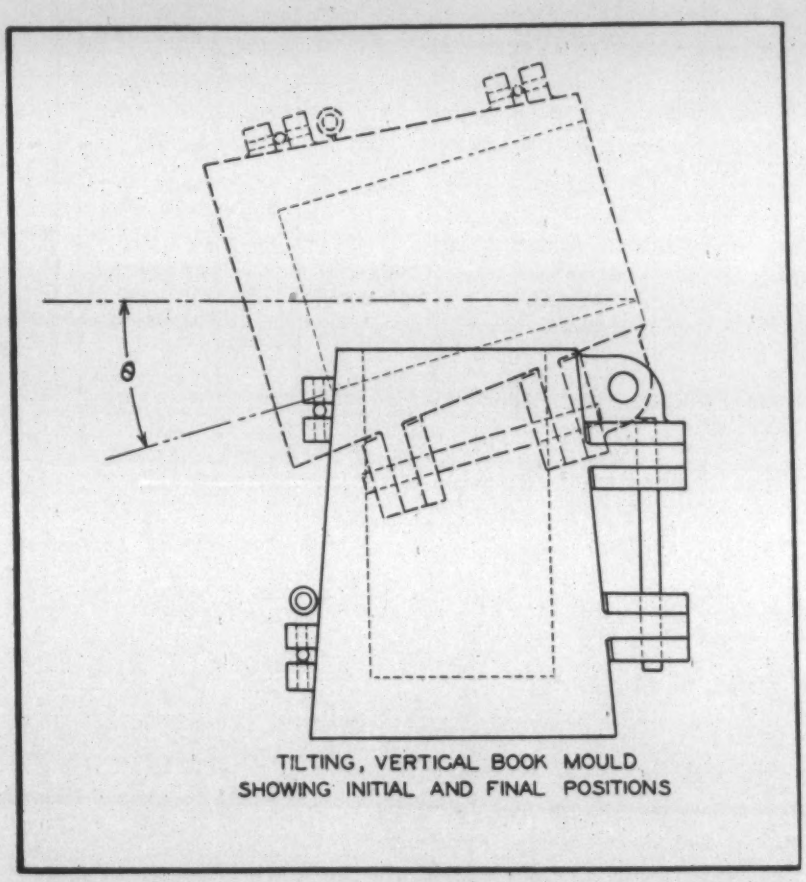


Fig. 1. Initial and Final Positions of Mold in the Casting Process.

HEAT EXCHANGE

Probably the most important consideration in the casting of billets for rolling into sheet is the rate at which heat is dissipated from the billet during solidification. The heat exchange is controlled by the mold construction, the method of cooling and the temperature of the metal being poured. These factors may be varied in a vast number of ways, and various methods have been employed to insure a uniform dissipation of heat from the entire casting. Uneven heat losses cause thermal stresses to be set up in the solidifying casting, and the ingots when removed from the molds tend to crack. The tapered mold, such as is shown in Fig. 1, has been employed to control and equalize heat dissipation. It permits shorter pouring times, since the sections of increased cross-sectional area of the mold are at such points as to permit rapid dissipation of the heat. Such a design reduces the likelihood of marked thermal stresses being set up, and produces a more or less uniform cooling rate of the metal. The two large cast hinges also aid in increasing the rate of dissipating heat, and thus permit more rapid pouring than was possible with bolted steel hinges.

When the castings are about 50° F. above the hot rolling temperature (800° to 900° F.), they are removed from the molds. The time required in the mold is dependent upon the conditions existing in the casting room, and whether the ingots are to be rolled directly or allowed to cool to room temperature for preheating. Immediately upon removal of the ingot from the mold, the latter is cooled either by the use of external water sprays fitted around its top or by internally cast water jackets. Jackets have not been used extensively under operating conditions.

Various procedures were followed in investigating the heat exchanges occurring during casting and cooling at varying mold and casting temperatures. With a proper combination of mold and pouring temperatures it is often possible to produce good ingots and still reduce the time the metal is left in the mold, by allowing the water spray to play on the mold during the pouring operation. This method, which produces very rapid chilling, was followed when it was desired to increase the thickness of the layer of the columnar crystals, in order to determine the planes of weakness in the ingot.

Various ideas are held regarding the proper operating temperatures for molds. In some plants sufficient molds are available, so that each mold can be cooled to room temperature before another casting is poured. The molds are not used at room temperature, but using a large number of molds permits operating them at uniform temperatures. Where only a limited number of molds are available, it is generally necessary to resort to some method of artificial cooling, in order that the mold will be ready for the next pouring in a comparatively short time. Generally hot molds are required for the production of homogeneous aluminum rolling billets. On the first round, the molds may be preheated by external burners or by pouring a quantity of hot metal into each mold and allowing it to freeze and remain in the mold until the latter has reached the required temperature for casting. The ingots in this case are not headed but are removed and returned directly to the melting furnace.

In some mills molds are operated as low as 200° F., while in some continental mills working temperatures are as high as 600° F. Mold life is materially reduced with the higher working temperatures, and the results of this work do not indicate that there is any advantage derived from such practice. As a matter of fact, high mold temperatures are productive to the formation of blisters. Under normal conditions molds appear to produce more homogeneous ingots when the mold temperatures are in the range 350° to 450° F. It is not easy to control such temperatures accurately by artificial cooling, and it is practically impossible to cool the molds uniformly except by natural air cooling.

The latter requires a large number of molds and slows up production.

Even though they are poured in the same manner, different alloys behave differently in regard to piping. Fig. 3 shows the types of pipes resulting from the compositions used. The solidification shrinkage in the case of pure aluminum is a function both of temperature and degree of purity, and, as will be readily noted from the figure, a very marked difference occurs in the volumes of the respective pipes. The 6 castings shown in Fig. 3 were poured as described and allowed to solidify without any further addition of metal to take care of the piping. Edwards and Gammon[2] have shown that aluminum and its alloys contract slowly and uniformly in cooling until the freezing point is reached, at which temperature a large contraction in volume takes place during solidification. When an ingot of this nature is poured, the metal in contact with the walls of the mold solidifies first, producing a shell of solid metal over the entire surface, the thickness of which depends upon the temperatures of the metal and mold. This shell grows as freezing progresses. Owing to the contraction of the metal on solidification the level of the molten metal is gradually lowered during the freezing process, and unless additional metal is supplied cavities of the type shown in Fig. 3 will form. In the commercial production of rolling billets, however, the pipe is not actually allowed to form, as metal is added continually, by means of a hand ladle, until the entire casting has solidified. The solidification shrinkage of pure aluminum is much greater than that of the commercial product or of secondary aluminum. The castings, shown in Fig. 3, were allowed to take their normal shrinkage, removed from the mold at 1000° F., and cooled to room temperature, after which one-half of the face of the billet was removed by milling. These slabs were polished and etched with 10% hydrofluoric acid to determine the relative areas occupied by the columnar crystals and the equiaxed grains. Differences in mold temperatures, which are not apparent in most cases, are often readily detected by following the above procedure, and very slight variations may be noticed by observing the relative areas occupied by the 2 types of structure present in the cast ingot. No. II in Fig. 4 shows the increased area occupied by the columnar crystals on the pouring side of the mold, that had been cooled 200° F. lower than the opposite side.

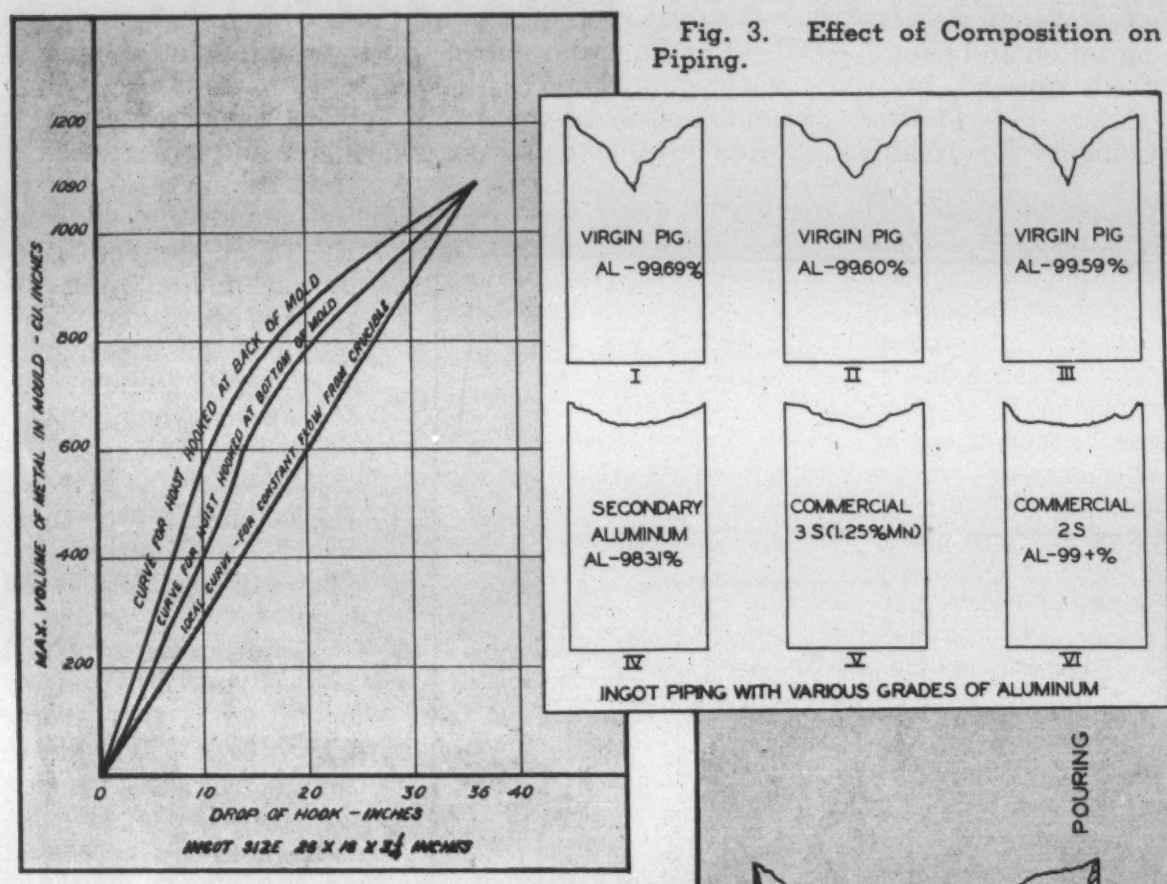


Fig. 3. Effect of Composition on Piping.

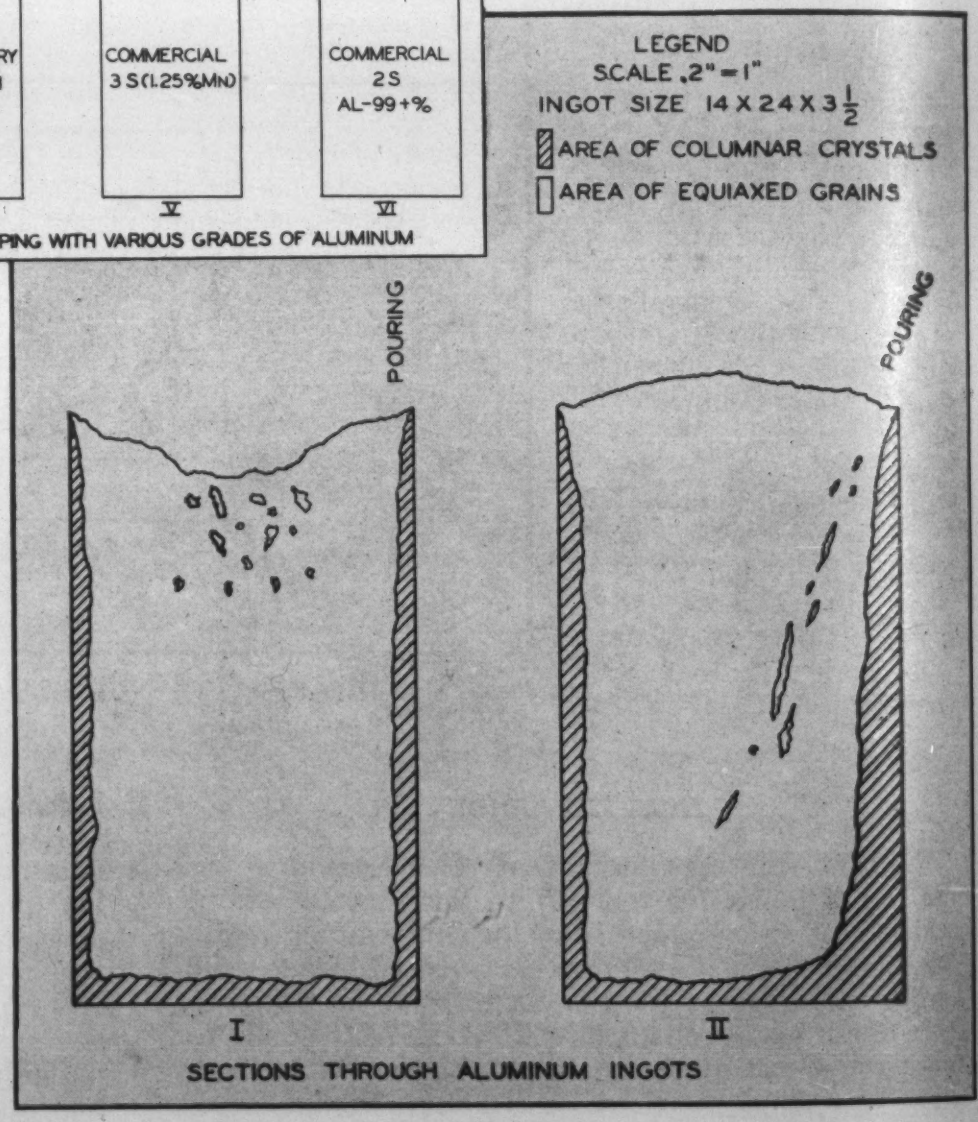


Fig. 4. Sections through Aluminum Rolling Billets Showing Porous Areas.

Fig. 2. Curve for Volume of Metal in Mold at Various Positions.

No appreciable difference in the casting properties of the compositions employed was noticed. Each behaved in very much the same manner, and no apparent difference was observed in the number of defects. Each, of course, possessed certain distinct casting properties, particularly differences in solidification shrinkage, but this did not appear to have any influence on the amount of defects arising from the respective ingots.

In addition to the variation of factors already referred to, numerous experiments were made on the machining of molds to determine the most suitable finish of the mold wall and its influence on the for-

[2] J. D. Edwards & H. T. Gammon. Causes of Piping in Aluminum Ingots. *Chemical & Metallurgical Engineering*, Vol. 24, 1921, pages 338–340.

mation of defects. A series of molds of the type previously referred to were machined in the following manners:

Highly polished surface.
Smooth cut on planer.
Rough cut on planer.
Rounded corners (champfer).
Slightly concave walls.

The various finishes did not show appreciable differences, and the tests failed to verify the prevailing ideas that the finish of the mold determines to what extent cracking will take place. There is some evidence, however, in favor of a very smooth wall face, such as that obtained by polishing. The champfered molds were tried primarily to relieve any tendencies to stick to the corners during the process of freezing and shrinking. Sticking would set up severe mechanical stresses, which in combination with thermal stresses could cause cracks.

Each ingot cast in the experimental work was cut in sections to permit study of the structure and was subsequently rolled into sheet, which was examined for defects.

Fig. 4 shows the condition found in two billets, cast under the same conditions, except that the pouring side was some 200° cooler in the case of II. In one case (I) the metal was allowed to take its normal shrinkage, and in the other (II) molten metal was added to fill the pipe, using commercial practice. The porosity shown was not evident until the last cut in machining, and appeared in each case to assume characteristic positions, depending on whether or not the billet was headed. Duplicates of each of the castings were prepared under the same conditions as the first set, the same porosity being found and in the same general parts of the ingot. A third set was prepared and rolled to 24 B & S gage coil, and the type of defect shown in Fig. 5 was found scattered throughout the coil. The porosity, although limited to a comparatively small volume of the ingot, would normally have caused the complete rejection of the sheet produced from it. The three sets of castings were in each case poured under the following conditions:

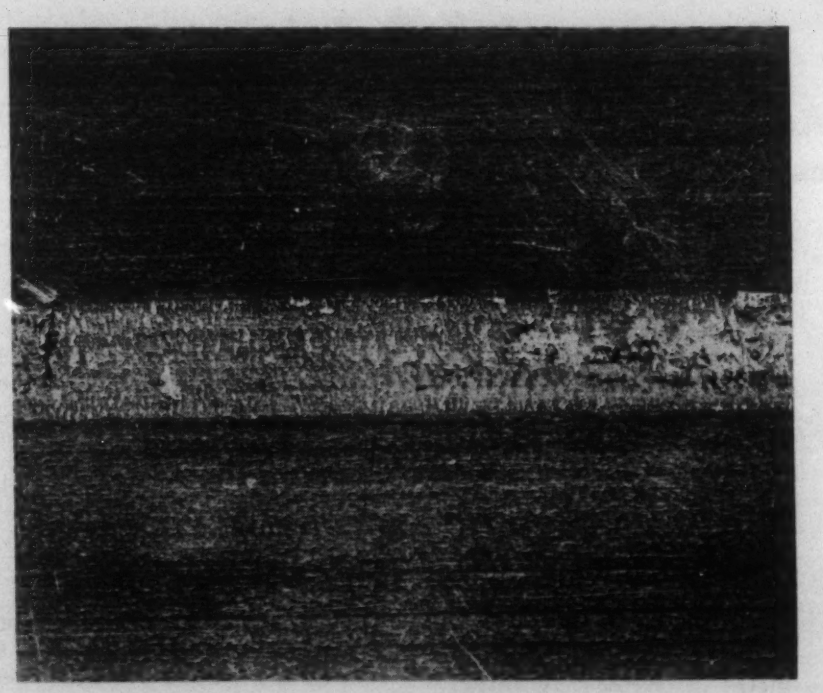


Fig. 5. Scale Sliver.

Temperature of metal on tapping from furnace	1450° F.
Pouring temperature	1300° F.
Mold temperature:	
Pouring end (II)	150° F.
Remote end (II)	350° F.
Pouring end (I)	350° F.
Remote end (I)	350° F.
Pouring angle (Θ)	5°
Pouring time	40 sec.
Heading time	3 min.
Temperature of ingot on removal from mold	950° F.

By duplicating the above experiments and changing the pouring time from 40 sec. to 3 min., and by increasing the pouring temperature from 1300° to 1350° F., the ingots were free from porosity, except in the case of the one which was not headed. In this instance there existed only a slightly porous condition in essentially the same area.

In the castings observed, cracks, often extending the entire length of the ingot, developed at the interface where the columnar crystals and the equiaxed grains meet. By increasing the chilling effect, that is, operating the mold at a lower temperature and, therefore, increasing the thickness of the layer of columnar crystals, it was possible to throw the cracks farther into the billets corresponding to the position of the interface.

The mechanism of freezing in an aluminum ingot of this type may be briefly summarized as follows. As the mold is filled, the metal that comes in contact with the walls of the mold is rapidly chilled, forming long columnar crystals. These crystallites grow in a direction opposed to that of the heat emission, but their growth is gradually retarded, owing to the insulation from the walls by the layer of metal already solidified. That part of the metal which has set therefore presents a saw-tooth appearance, upon which a different type of crystal will form, extending in different directions and filling the interstices of these teeth. From this point crystallization proceeds at a more uniform rate, starting from myriads of nuclei, which grow as cooling continues, thus leaving the central portion of the casting occupied by equiaxed grains. That portion of the ingot at which the growth of the columnar crystals has been retarded, and where the equiaxed grains fill the interstices, offers less resistance to the mechanical stresses, encountered in rolling, than if the billet consisted entirely of one type of grain. Cracks set up either by thermal stresses during solidification or by mechanical stresses on rolling can generally be traced to this locality of mixed grains.

In a series of experiments the cracks were found to fall directly at the point where the 2 types of grains joined, wherever the interface was moved to by controlling mold and pouring temperature. Such cracks appear either on removal of the ingot from the mold or after it has been subjected to stresses in hot rolling. Whether such cracks develop as a result of mere weakness at a crystal boundary, or if a plane of weakness exists at this point for some other reason, cannot be stated with certainty. It is to be expected that the ductility of the columnar crystals will be less in the direction of the shorter axis than in the direction of the longer axis, but no failures were observed in this area of columnar crystals, while in some cases cracks develop in that portion occupied entirely by equiaxed grains. The greater number of cracks, however, occur at the junction of the 2 types of grains.

A number of such cracks were examined both macro- and microscopically. The structures in each case appeared to be normal, showing moderately small grain size, with evidence of small quantities of the iron-rich phase arranged in a dendritic fashion in the outer envelope and in a polygonal fashion in the middle portions. The cracks in each case appear to follow crystal boundaries. The presence of the iron-rich phase was

particularly noticeable in the case of ingots produced from secondary aluminum. Cracking in each type of product was, however, of the same nature.

The blistering of aluminum and aluminum alloy sheets is one of the largest problems encountered in fabrication. Although improvements in processes have greatly decreased the percentage of this defect in the final product, much still remains to be done, since more sheet is rejected on account of blisters than any other defect. There are certain precautions, however, which when carefully executed, materially decrease rejections of this nature, and of these the following are of importance:

Avoidance of high melting temperatures.
Low pouring temperatures.
Slow pouring speeds.

Melts which have been exposed to high temperatures for any length of time generally show large percentages of blisters in sheets rolled from those melts, and the same is true where high pouring and mold temperatures are employed. If reasonable care is exercised in the melting and casting operation, a minimum of blistering will result. Fast pouring speeds are favorable to the formation of blisters, since a certain amount of undue agitation takes place which can be avoided only by increasing the time required to pour or by decreasing the angle (Θ), if it is above 10°. Dissolved gases and entrapped air, which are not liberated during the casting process, are both causes for blistering in sheet. Blisters generally become evident only after annealing, since at annealing temperatures these included gases expand and force the soft metal to expand.

The results of work of this nature cannot be expressed in quantitative values, owing to the difficulty of correlating the data. In such work it is always necessary to make a large number of duplicate tests before the results obtained can be accepted. Even then the results are not always enlightening, since the effect of the various changes in practice has to be measured by observing the condition of the finished sheet. This is oftentimes very unsatisfactory, owing to the factors not traceable to the melting and casting operation.

Under the conditions specified, aluminum rolling ingots can be produced containing a minimum number of defects by careful observance and control of the following:

1. Melting temperatures not to exceed 1500° F.
2. The use of a flux which will thoroughly clean the metal.
3. Low pouring temperatures.
4. Small tilting angle. Θ less than 10°.
5. Uniform and slow pouring speed.
6. Tapered molds.
7. Air cooling of molds where possible.
8. Smooth mold finish.
9. Mold temperatures not exceeding 450° F.

◆ ◆ ◆ ◆ ◆

Current Committee Activities in American Society for Testing Materials

Committee A-2 Wrought Iron is preparing a detailed discussion of what constitutes "quality" in wrought iron.

The Committee on Cast Iron is actively engaged in an investigation of impact testing. Twenty-three special sets of test bars were poured at various foundries representing a large number of commercial cast irons. Tension test specimens have been machined from all of these sets and tension tests, including elongation determinations, have been made. The fatigue tests are well under way, while approximately one-half of the transverse tests have been made. Considerable work has been done on the chemical analyses of these irons.

Various impact tests will be made on the series of test bars with the object of determining a satisfactory impact test for cast iron.

This work will probably be completed in time so that a report can be made at the 1932 Annual Meeting.

This committee, A-3, will also undertake the development of test bars which will represent the metal in the casting rather than the metal in the ladle.

A subcommittee has prepared an extensive digest of the literature on the heat treatment of cast iron, for future publication.

Committee A-7 on Malleable Castings is planning an investigation of the embrittlement of malleable iron castings which are used in the galvanizing process. A subcommittee will probably be formed to make a critical study of this phenomenon.

Specifications for cupola malleable iron are under development by the committee and a revision is contemplated of the specifications for malleable castings to meet higher strength requirements, particularly for railroad work.

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys has sponsored the preparation and distribution of 16,000 specimens of many different materials. These will be exposed in nine outdoor test locations and in four different liquid immersion test locations for exposure tests. All specimens have now been placed on the racks at the following test sites:

	Test Sites	Types of Atmosphere
1.	Pittsburgh, Pa.	Industrial
2.	Altoona, Pa.	Industrial
3.	State College, Pa.	Rural
4.	New York City	Combination of semi-industrial and partial seacoast exposures
5.	Sandy Hook, N. J.	Northern seacoast
6.	Rochester, N. Y.	High humidity, light industrial
7.	Key West, Fla.	Southern seacoast
8.	Phoenix, Ariz.	Dry inland
9.	San Diego (La Jolla), Calif.	High humidity, seacoast

The committee plans to review data which was obtained on accelerated corrosion tests and to write recommended practice instructions for total immersion, alternate immersion, spray and accelerated electrolytic tests together with a critical review of each.

Committee B-7 on Light Metals and Alloys is contemplating the preparation of specifications for aluminum alloys in the form of forgings suitable for engine crankcases, locomotive parts and miscellaneous forgings. A specification for Alclad, an aluminum-coated material, is under preparation. This material is finding considerable application in aircraft construction as it eliminates corrosion embrittlement to which uncoated aluminum alloys are subjected under more severe corrosive conditions.

This committee is also arranging to carry on a series of tests to ascertain the best methods of determining the proportional limit for cast and wrought light alloys.

A special Subcommittee on Grain Characteristics of Steel has been organized to study grain sizes of steel and the spheroidizing of tool steels.

The outline includes the preparation of grain size charts for carburizing steels, for forging steels and for tool steels. Possibly sheet steels will be included at a later date.

◆ ◆ ◆

John S. Bleecker, who has been appointed Manager of Sales of Lukenweld, Inc. (Division of Lukens Steel Company), Coatesville, Pa., was graduated from the Massachusetts Institute of Technology in 1898. He began his career with the American Bell Telephone Company. Most of his activities for the next 27 years from 1901 to 1928 were confined to executive management of many enterprises for Stone and Webster, Day and Zimmermann and Bates, Inc. From 1928 and until his association with Lukenweld, Inc., in 1931, he was a registered professional engineer engaged in industrial and public utility work, specializing particularly in transportation and merchandising.

CENTRIFUGAL CASTING of METALS and ALLOYS

BY J. E. HURST*

AN EARLY British Patent dated 1809 in the name of Anthony Eckhardt of Soho, Birmingham, claims the invention of a centrifugal casting process embodying "the use of molds revolvable with their axes either vertical, inclined or horizontal in order that centrifugal force due to the revolution may press the fluid metal against the interior surfaces of the mold and more perfect castings thereby produced." The use of a grooved cylindrical mold with longitudinal grooves in its interior surface and revolving about a horizontal axis was claimed also for the production of straight bars. While there are a number of different processes of centrifugal casting in commercial operation to-day, the broad principles outlined in this early patent are common to them all. In operation, the centrifugal casting process is applied to castings of an essentially cylindrical character. The mold is arranged to rotate with its central axis either vertical, inclined or horizontal. The internal periphery of the mold is of the shape of the external form of the casting required. No core is used or required for the formation of the main internal surface of the casting and suitable and closing walls are provided to prevent the displacement of the liquid metal in the direction of the axis of rotation. The molten metal is introduced into the rotating mold by suitable means and the centrifugal forces resulting from the rotation of the liquid metal tend to distribute it toward the inner periphery of the mold. When solidified, the metal produces a hollow casting, the external shape of which corresponds to that of the internal shape of the mold. The internal bore of the casting as defined by the end walls of the mold is either truly cylindrical or of a more or less paraboloidal form in those cases where the mold is rotated about an axis inclined to the horizontal.

In the commercial application of the process, its limitation to castings of a cylindrical character by no means restricts its importance and commercial value. Closer acquaintance with the process rapidly discloses that its applications are very much larger than one would suppose. Many engineers and designers have been intrigued by the possibilities of this process and have undertaken development and experimental work with a view to adapting the process to their specific requirements. The centrifugal process is now applied in most industrial countries to the production of castings of cast iron, steel and non-ferrous alloys.

* Sheffield, England.

General Properties of Centrifugal Castings

In the early patent referred to previously, it is claimed that by the centrifugal process more perfect castings are thereby produced. Probably this claim is the most important of the advantages of the process and the properties of the castings produced by the process.

The conditions under which the liquid metal exists in the mold throughout the centrifugal casting process are different in certain important respects from those in sand casting. Considering a casting of simple cylindrical form in the sand casting process, generally such a casting is made vertically. In such a mold filled with molten metal, the metal commences to solidify almost simultaneously from the outside and inside surfaces, respectively. Under these circumstances, all the segregates, impurities and dissolved gases tend to be concentrated in the center of the radial thickness of the metal and in the head which is commonly provided to enable their effect to be minimized, as illustrated in Fig. 1. In the centrifugal process, the mold is filled with metal in a direction at right angles to that in which the cooling takes place in the vertical sand mold, and solidification of the metal commences from the outside surface only, and proceeds across the radial thickness of the casting progressively until the whole is finally solid; the inner surface layers being the last to solidify. If we imagine the instant at which solidification commences to occur, the metal lying against the mold wall is liquid, and has acquired the rotational velocity of the mold. Under these conditions, a centrifugal pressure gradient is established across the radial thickness of molten metal, the pressure being at a maximum in the outside diameter layers of molten metal, and zero on the extreme inside diameter layers. This maximum pressure is often of the order of 500 lbs./in.^{2} The dissolved gases liberated by the solidifying layers which first commence to solidify on the outside surface must make their way through the radial thickness of still liquid metal. It will be noted in passing, that this is a much shorter path than the vertical length of the casting in

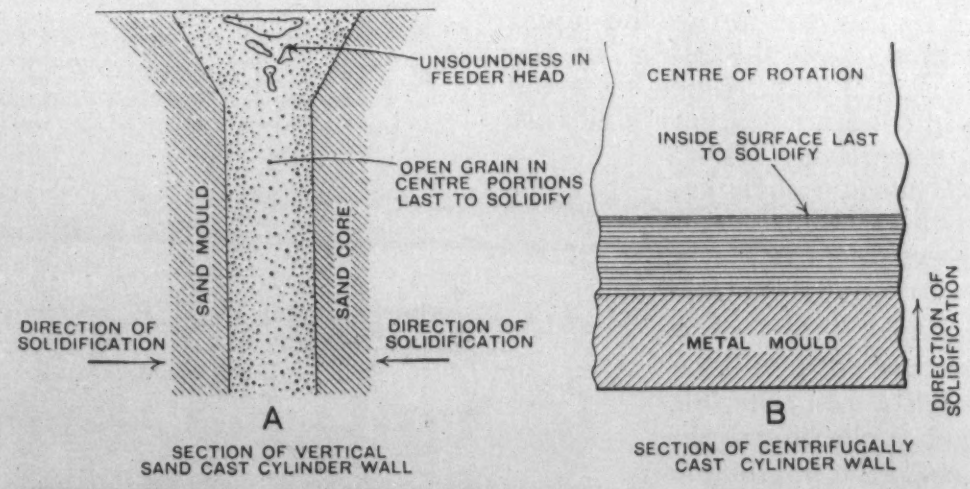


Fig. 1. Diagram illustrating difference in the process of solidification between vertical sand castings and centrifugal castings.

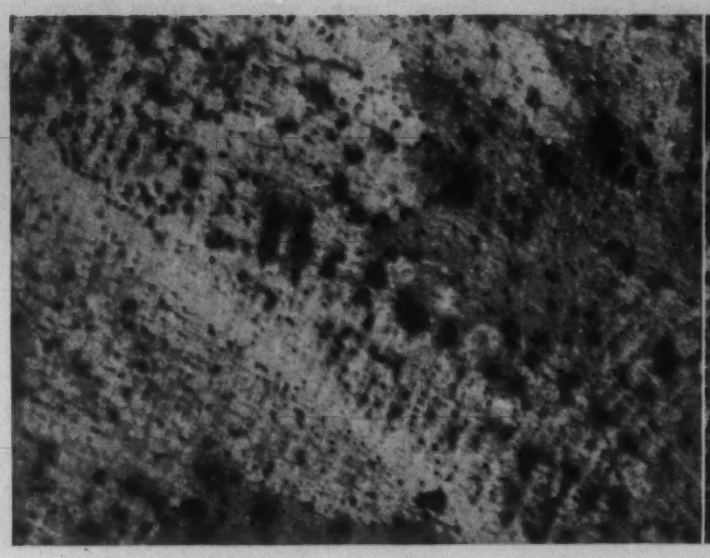


Fig. 2. Chill cast bronze. Showing large crystal grains. Etched with Stead's reagent. Mag. 75×.

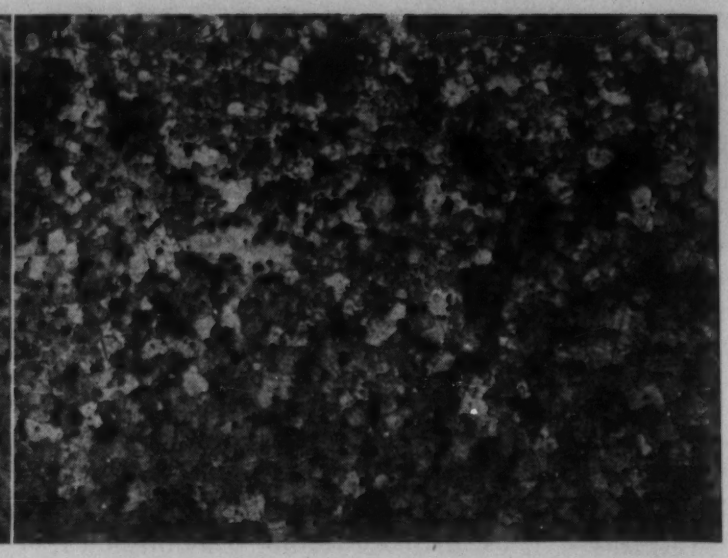


Fig. 3. Centrifugally cast bronze. Showing small crystal grains. Etched with Stead's reagent. Mag. 75×.

the vertical sand casting case. The passage of the gases through the radial thickness is assisted so enormously by the steep pressure gradient that we may say the gases are actually forced out by the centrifugal pressure, and that for all practical purposes it is impossible for blowholes or internal unsoundness of the ordinary character to exist in castings made by this method.

Another general property of castings made by the centrifugal process is their extreme closeness and fineness of grain size. This is a matter of common observation and would appear to be true for all the metals and alloys cast by this process. It is possible that this effect is to be ascribed to the rotation of the liquid metals during solidification. An illustration of the effect is to be found in Figs. 2 and 3 which show the crystal grain structure in a common bronze chill cast and centrifugally cast, respectively. Both illustrations are shown at the same magnification. The effect of this fine grained structure is revealed in the examination of the strength properties of centrifugally cast materials.

Centrifugal Cast Iron Castings

If tonnage output be taken as a criterion, by far the most important application of the centrifugal casting process is the production of cast iron straight socket pipes for sewage, water and gas mains. It is safe to say that this process is steadily displacing the ordinary methods of vertical sand molding of pipes in the principal pipe foundries throughout the world.

On metallurgical grounds the application of this process to the production of general centrifugal castings is by no means of less importance. In this application the process has been developed extensively in Great Britain and has progressed to a greater extent in this country than in any other. Cylindrical castings for piston ring manufacture, locomotive piston valve liners, cylinder liners for motor engines, internal combustion engines, steam engines, compressors, pumps, liners for brake drums, renewable valve seats and packing rings are a few of the many applications of centrifugal castings in cast iron for general purposes. A group of cylinder liners for various purposes, and a group of locomotive piston valve liners are illustrated in Figs. 4 and 5.

Chemical Composition and Properties of Centrifugal Cast Iron

The material requirements of automobile piston rings are covered by the British Engineering Standards Association Specification No. 5004 and the Air Board Specification 4K6 and have been evolved as a result of considerable experiment and investigation undertaken jointly and severally by the above-mentioned bodies. The chemical composition requirements are the same in both specifications as follows:

Total Carbon.....	not more than 3.50%
Combined Carbon....	between 0.45% and 0.80%
Silicon.....	between 1.80% and 2.50%
Manganese.....	between 0.40% and 1.20%
Sulphur.....	not more than 0.12%
Phosphorus.....	not more than 1.00%

Fig. 4. Group of centrifugally cast locomotive piston valve liners.

The mechanical test requirements consist of a tensile test and an elasticity value. The tensile test is performed on a ring cut from the drum, to an approximately square section or to a section approximately that of the finished ring. The ring is split and pulled apart in a testing machine by a load applied at opposite ends of the diameter which is at right angles to that through the gap. The ring must withstand a stress of at least 16 tons/in.^{2} before fracture, calculated from the following formula:

$$S = \frac{PD}{1200\,bt^2}$$

Where S = Stress in tons/in.^{2}
D = External diam. of closed ring in inches.
P = Load in pounds.
b = Width of ring in inches.
t = Radial thickness of ring in inches.

The elasticity of the material is the property which determines the spring in the ring or the pressure it exerts on the cylinder wall. It is, of course, well known that the elasticity value of cast iron is not constant over a stress range as in the case of steel but varies progressively with an increase in stress. In view of the fact that the dimensional specifications for piston rings include the minimum and maximum cylinder wall pressures exerted by the rings which are calculated from a formula in which the elasticity value determined under certain well defined conditions is used, it is necessary to embody this elasticity test in the material specification. The elasticity test requirement of the specification determined under these defined conditions is referred to as the En value, and must not be less than 15.5 million lbs./in.^{2} This is an exceptionally good value for cast iron, and centrifugal castings exceed this by an amount of generally from 1 to 2 million pounds.

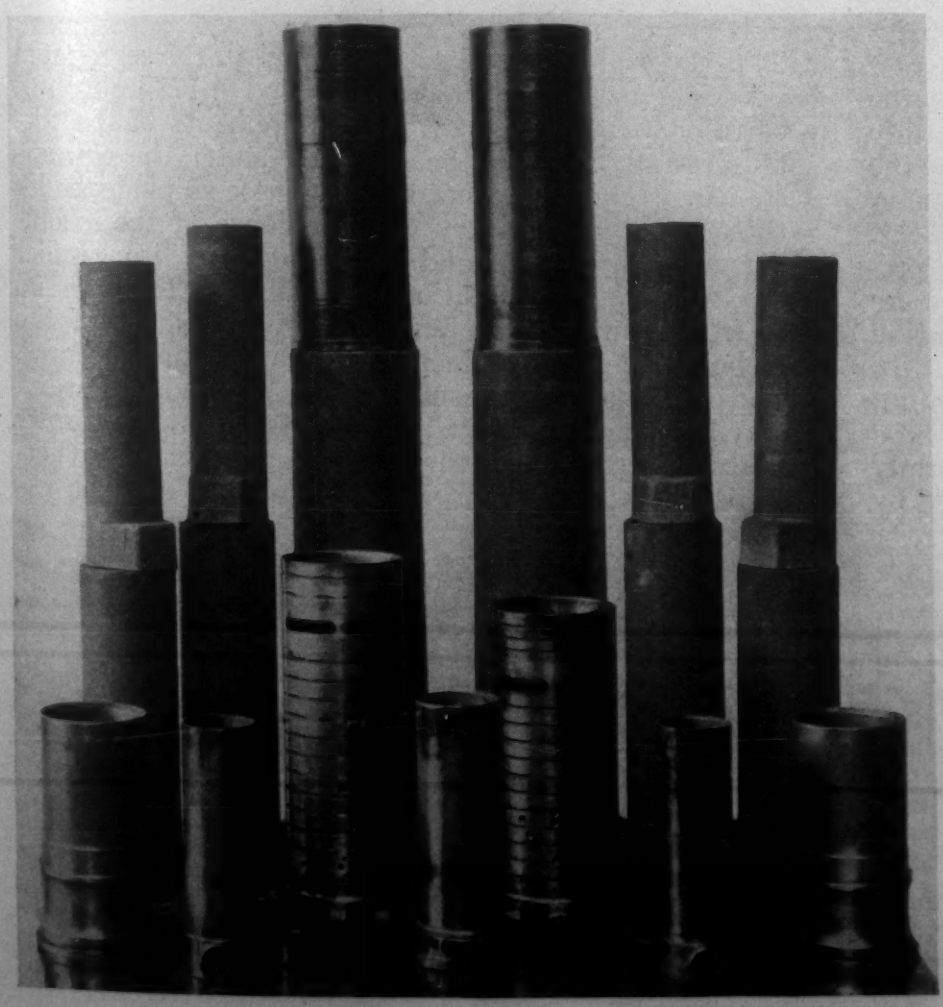


Fig. 5. Group illustrating various types of centrifugally cast cylinder liners.

Fig. 6. Centrifugally cast "Spun Sorbitic" cast iron. Etched with picric acid. Mag. 200×.

Spun-Sorbitic Centrifugal Cast Iron

This development is designed to enable cylindrical castings to be produced by the centrifugal process in low silicon, low total carbon irons with the maximum of combined carbon compatible with commercial machinability.

When the material used in this process is allowed to cool down normally, the whole of the combined carbon is found to be in the structural condition known as pearlite. Cast iron of this compostion when quenched in water, like steel, is hard, due to the fact that this constituent exists in the form of martensite. Again, as in the case of steel, if the rate of cooling is hastened somewhat above the normal, an intermediate structure between pearlite and martensite is obtained, still freely machinable, known as sorbitic. In this new process, the casting during cooling down and while rotating in the centrifugal casting machines is subjected to the action of a wet air blast suitably regulated and applied to the internal surface. The hastened cooling resulting from this treatment results in this sorbitic structure. This is distinctly advantageous since it is known that this structure is highly resistant to wear. The structure of the finished casting made by this process is illustrated in Fig. 6. It is a matter of considerable interest to note from a practical point of view that the special treatment is applied to the whole of the inside surface of the casting, which is generally the wearing surface of cylinders.

Alloy Cast Irons

The centrifugal process lends itself admirably to the production of castings in alloy cast irons and overcomes the difficulties arising normally out of the higher shrinkage value of these irons. These alloy cast irons are now extensively used in the production of centrifugally cast liners for motor vehicle engines. The more strenuous demands of modern automobile engine construction brought about by such considerations as increased piston speeds, the use of aluminum alloy pistons particularly in commercial vehicles has led designers to reconsider the question of cylinder design in which the cylinder bore can be made more definitely resistant to wear. Two alternative methods of construction present themselves in both of which the properties

of centrifugal castings are of inestimable value. One construction now known as the "wet" liner consists of a form in which the cylinder barrels are constructed separately and inserted into a more or less simple form of outer casing or water jacket. The alternative method utilizes the existing type of monobloc cylinder casting into the cylinder bores of which thin liners are pressed. This method is known as the "dry" liner method. Both these constructions have been developed extensively and various types of centrifugally cast alloy cast irons are utilized for this purpose.

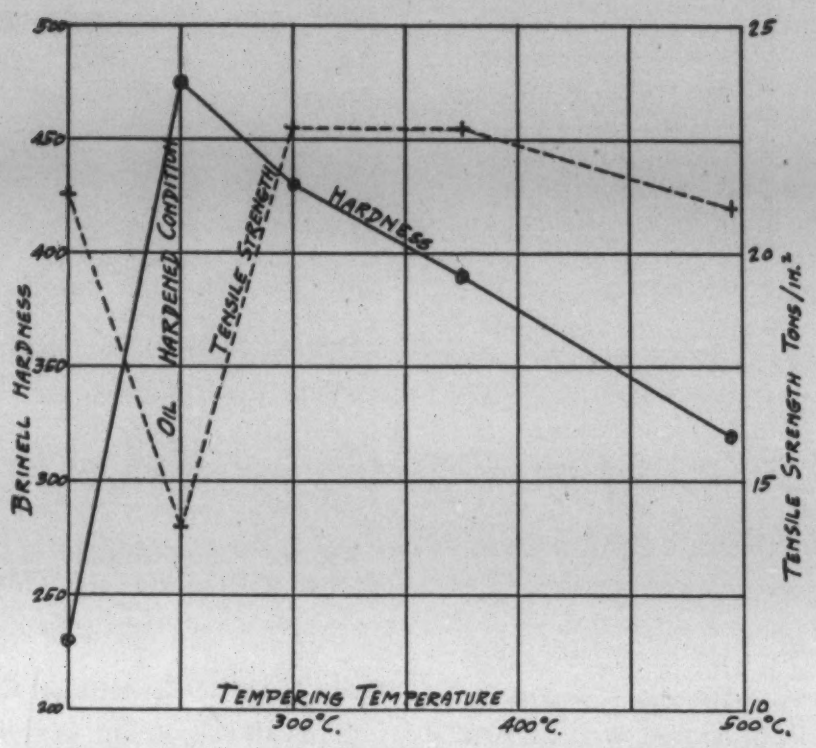


Fig. 7. Properties of hardened and tempered liners. Treatment: Quenched in oil from 875° C. Temper for 10 minutes in salt bath at temperature corresponding to desired Brinell hardness.

Alloy cast irons containing varying quantities of such alloy additions as nickel, chromium and manganese are produced. Cylinders in these alloys are used in both the normal "as cast" condition and in the hardened and tempered condition. Alloy cast iron suitable for hardening either by oil hardening or air hardening are produced. The properties developed by such treatments are illustrated in the typical diagram, Fig. 7. In addition to these both direct martensitic cast irons and austenitic cast irons are produced by the centrifugal process. This latter type of cast iron finds extensive use for those purposes where cast iron having a high coefficient of expansion is required.

The fact that the molten cast iron when in the rotating mold is subjected for a time to the influence of centrifugal action adds considerable interest to the study of the distribution of the various constituents across the radial thickness of the casting. The results of a study of the distribution of the various elements across the radial thickness of 12″ diameter and 8″ diameter Stanton-de Lavaud spun pipes have been given by Fox and Wilson. These results have been determined presumably on the castings after annealing, and they are illustrated in Fig. 8. A further similar investigation has been carried out by Pardun of Gelsenkirchen. In this instance the results have been determined on unannealed castings. The results of Fox, Wilson and Pardun agree that the silicon is more or less uniformly distributed throughout the section, and is unaffected by the centrifugal action. Both manganese and sulphur show a marked segregation toward the inside surface, and are found to be concentrated in the extreme inside layers. The results of the phosphorus determinations show that this has the tendency to be concentrated toward the outer layers and a distinct zone of higher phosphorus content is disclosed close to, but definitely underneath, the outermost layers. In the case of the carbon contents, the results of these two investigations differ. Fox and Wilson found a slight tendency for the total carbon contents to increase in the direction of the inside of the casting, while Pardun's results show exactly the opposite effect. Similarly, with the graphite, the marked increase in the direction of the inside surface is to be compared with Pardun's results, in which the graphite behaves very similarly to the phosphorus.

The sulphide segregation is undoubtedly due to the centrifugal action on the manganese sulphide particles. Chemical analyses taken from the segregated portion and the body of a casting gave the following results:

	Manganese	Sulphur
Segregated portion.....	0.60%	0.23%
Body of casting.....	0.33%	0.06%

The excess of manganese and sulphur in the segregated portion, viz., 0.27% manganese and 0.17% sulphur, correspond as closely to the requirements of the formula MnS as could be expected under the circumstances. The movement of manganese sulphide under these conditions is very clear evidence of the insolubility of this compound in molten cast iron under the temperature conditions prevailing. There is no clear evidence of any tendency of movement of the carbon under the influence of the centrifugal force. The difference in the results of Fox, Wilson and Pardun may be explained partially by the fact that the former analyses were made on the annealed material. Furthermore, the effects of primary segregation may be ex-

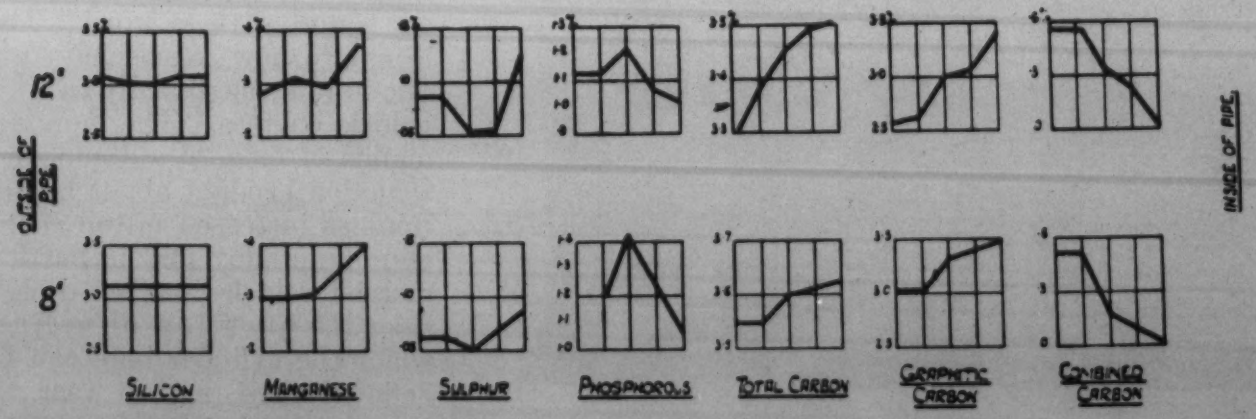


Fig. 8. Diagram showing distribution of constituents across radial thickness of centrifugally cast iron pipes (Stanton-de Lavaud).

pected to be prominent under the conditions of casting in metal molds independently of any consideration of centrifugal action. Suffice it is to say that the irregularities in distribution of the carbon constituent noted in the above experiments can be removed almost entirely by adjustment of the chemical composition; a fact which goes to prove that the irregularities noticed are not due to the centrifugal action. It is only right to record that Pardun, in discussing his results, states that "it was found that the conditions of casting, such as increasing the speed of rotation, varying composition and varying casting temperature, have no logical influence on segregation."

Microstructure

The structural characteristics of centrifugally cast iron naturally vary according to the characteristics of the particular process by which it is made. Obviously, there is a difference in structural character between cast iron spun in metal molds and that spun in sand molds. This difference is very noticeable in the appearance of the free carbon. Fig. 9 shows the character and distribution of the graphite typical of centrifugal castings made in metal molds, while Fig. 10 is typical of the graphite distribution of cast iron cast centrifugally in a sand mold. Both photographs are taken at the same magnification and the exceptionally fine form of the graphite in the metal mold centrifugal casting can be compared with the sand mold centrifugal casting. Incidentally, it is worth while pointing out at this stage that the degree of fineness of the graphite is not in itself directly related to the strength properties of the material. Of the two examples above illustrated, the one having the coarser graphite structure is by far the stronger of the two, as measured by the tensile strength.

Fig. 9. Showing distribution of graphite in centrifugal casting produced using metal molds. Unetched. Mag. 50×.

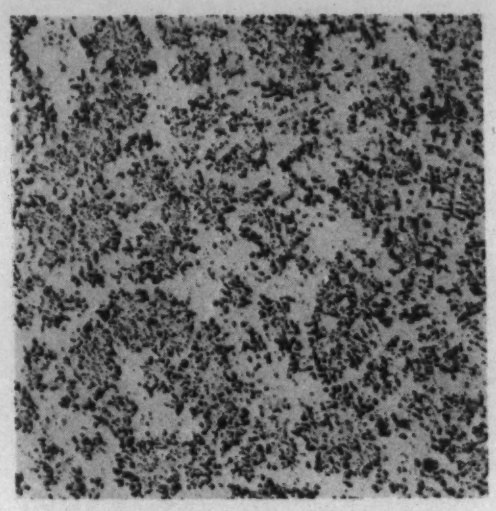
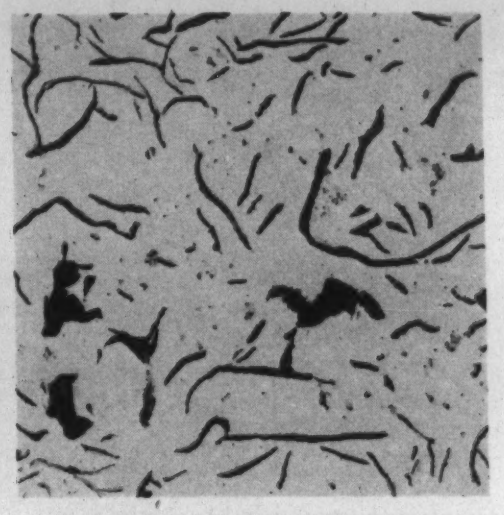


Fig. 10. Showing distribution of graphite in centrifugal casting produced using sand molds. Unetched. Mag. 50×.



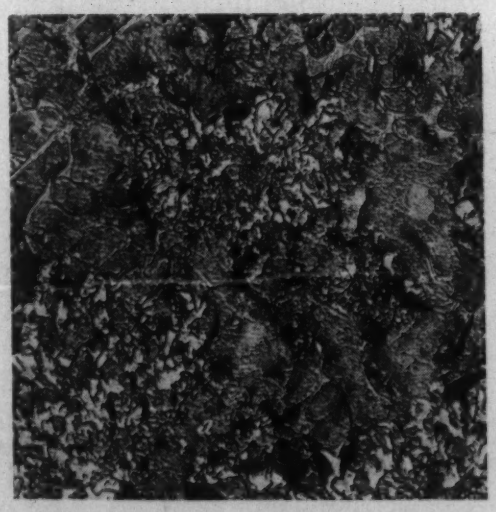


Fig. 11. Same as Fig. 9. Etched with picric acid. Mag. 200×.

Fig. 12. Same as Fig. 10. Etched with picric acid. Mag. 200×.

The etched structures of the same two samples at a higher magnification are illustrated in Figs. 11 and 12. These should be considered in conjunction with the chemical analyses of the two samples given below:

	Fig. 11	Fig. 12
Total Carbon	3.22%	3.25%
Combined Carbon	0.57%	0.89%
Graphite	2.65%	2.36%
Silicon	2.02%	1.58%
Manganese	0.77%	0.82%
Sulphur	0.08%	0.095%
Phosphorus	0.72%	0.66%
	Ref. 21459B	Ref. 21459C

In Fig. 11 in addition to the phosphide eutectic, the ground mass structure consists of pearlite and more or less defined colonies of ferrite. In the ground mass structure of Fig. 12 there is no ferrite, the whole structure consisting of pearlite some cementite and the phosphide eutectic. This difference in structural constituents is largely due to the lower silicon content, and of course has a large influence on the higher strength properties of this sample. In both cases the closeness and fineness of the different constituents will be noticed. This is a characteristic of castings made by the centrifugal process, and is, of course, reflected in the closeness of the fracture of such castings.

Centrifugal Steel Castings

The development of the application of the centrifugal process to the production of castings in steel has not been so extensive as in the case of cast iron. There are various reasons for this, of which probably the most important is the difficulty of maintaining a continuous supply of molten steel to enable continuous operation of the plant. This, of course, can be and is overcome, but not with the same ease as in the case of cast iron. The effect of centrifugally casting steel on the structural characteristics and physical properties of the steel has been ably dealt with in the Bureau of Standards Report No. 192, 1921. At the present time, the only application of the centrifugal process of any magnitude to the production of steel castings in England is the Davis steel wheel process, operating at John Brown & Company's Works, at Scunthorpe. This process is well known in England and America, and its principal object is to secure a manganese steel tread on the wheel. This is done in a very ingenious manner by the introduction of powdered ferro-manganese into the first portions of liquid metal which enter the rotating mold. By virtue of the rotation this high manganese portion of the steel is finally located in the tread of the wheel. The application of the centrifugal process to the casting of steel pipes, hollow ingots and annular billets for various purposes, is undoubtedly engaging the attention of many steel works engineers and metallurgists. At the Watertown Arsenal, U. S. A., the process has been adapted to the production of gun barrels. The McConway process for the production of annular blooms

has also been described (see Journal of Iron & Steel Institute 1921).

In the U. S. A. the production of cylindrical castings in alloy steels is being carried on commercially. A special process has been devised by Cammen for the production of steel bars or blooms. Small steel hollow cylinders or bushings were produced in England particularly during the War when they were used to a certain extent for aeroplane engine cylinder liners. The commercial requirements of small cylindrical steel bushings do not lend themselves to the same degree of standardization as in the case of cast-iron piston rings, a fact which has operated against more extensive development in this direction.

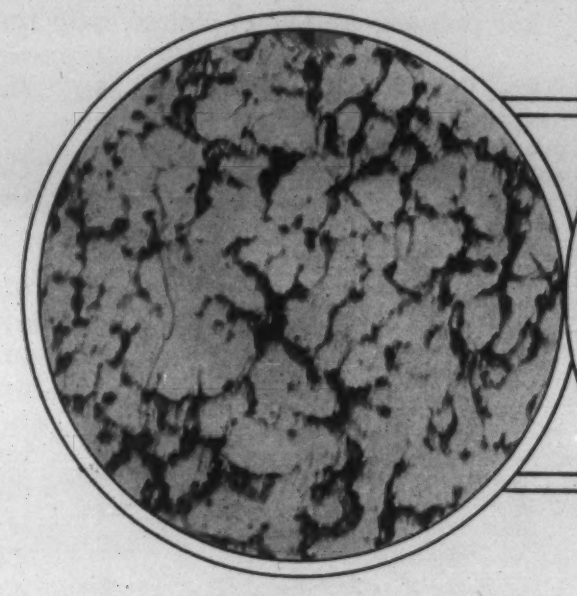


Fig. 13a. Chill cast ingot Monel metal. Mag. 200×.

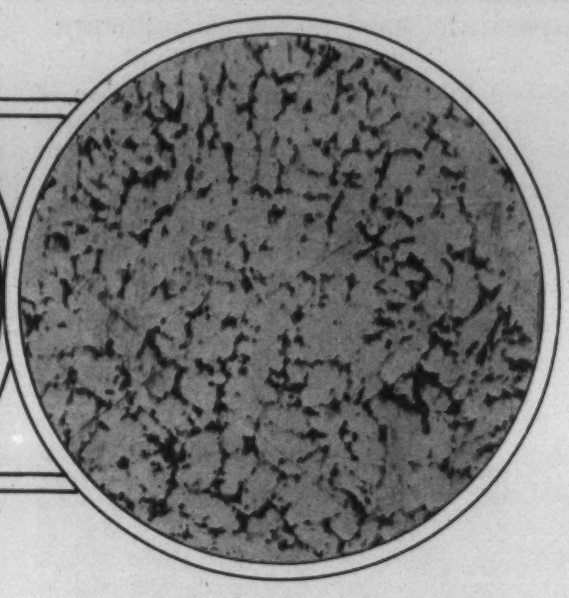


Fig. 13b. Centrifugally cast Monel metal. Mag. 200×.

Centrifugal Non-Ferrous Alloy Castings

Supplies of molten non-ferrous alloys available at almost any instant of time are not so easily organized as in the case of cupola melted cast iron. As in the case of steel, this is one of the difficulties to be faced in the extensive application of the centrifugal process to non-ferrous alloys. Furthermore, the amount of work available of a repetitional character and suitable for the application of the centrifugal process is limited.

In spite of this, there are several applications of this process of an extremely valuable nature to the non-ferrous industry. The difficulty of producing various brass and bronze sleeve castings sound and free from defects is almost proverbial. The sleeve castings referred to are those used for lining paper mill rolls, hydraulic cylinders and rams, pump liners and similar items. These latter may have been produced consistently in England and America for many years. The ability to produce these castings free from pinholes and similar defects is an outstanding advantage of the centrifugal process.

Cupro-nickel shell bands have been produced on an extensive scale in America by the centrifugal process. Nickel base alloys for valve seatings are produced similarly, and the process has been adopted on an extensive scale also for the production of worm wheel blanks in phosphor bronze and aluminum bronze, and the lining of bearings with anti-friction white metals. Cored bars in bronze are produced on a commercial scale in America. Generally speaking, with the exception of gear wheel blanks, sand molds have been consistently adopted in the production of cylinders by this process. One of the reasons for this is the lack of repeat requirements. Typical examples of non-ferrous alloy castings produced by the centrifugal process are referred to specifically below:

Monel Metal. It is not generally appreciated that Monel metal can be cast very satisfactorily by the centrifugal process. Cylindrical castings for valve parts, seats and discs, cylinder and pump liners, shaft sleeves and bushings have been cast extensively in Monel metal by the centrifugal process. The castings are made from ingot Monel metal, melted in coke fired crucible furnaces. The metal, deoxidized with magnesium, is cast into cylinders on the centrifugal casting machines. Metal molds are used and the castings possess the high degree of soundness and closeness of grain characteristic of centrifugal castings. The Brinell hardness of centrifugally cast Monel metal lies within the range of 140 to 160.

Silicon Monel Metal. A modified Monel metal containing silicon has given very satisfactory results when cast by the centrifugal process. This alloy is prepared by the addition of approximately 2.75% of silicon to remelted Monel metal. Centrifugal castings made from this alloy are completely sound and free from defects. The microphotograph Fig. 13 is characteristic of this material. The addition of silicon increases the hardness and tensile strength of centrifugally cast Monel metal. The values obtained on two samples of centrifugally cast silicon Monel metal are set out in the following table:

Table 1. Centrifugally Cast Silicon Monel Metal

Silicon Content	2.75%	3.09%
Ultimate Tensile Strength	43.70 tons /in.²	50.03 tons/in.²
Yield Stress	36.90 tons/ in.²	49.70 tons/in.²
Elongation	3.00% on $1^1/_2$ in.	8.00% on $4\sqrt{\text{area}}$
Brinell Hardness	207	...

The remarkably high yield stress of this alloy is worthy of special note. Rings machined from centrifugal cast cylinders have been examined for internal stress. The test rings when cut showed no change in gap, indicating complete freedom from internal stress.

Centrifugal Casting Processes

A number of different types of processes for the production of centrifugal castings are in commercial operation. In all cases the casting machines can be considered conveniently under the three essential headings:

(a) the means adopted for the rotation of the mold
(b) the method of pouring or introduction of metal into the mold
(c) the form and construction of the mold.

(a) **The Means Adopted for the Rotation of the Mold:** The most important aspect of the methods adopted for the rotation of the mold which warrants consideration here is the axis of rotation. In the principal processes in commercial operation, rotation of the mold about its horizontal axis or an axis slightly inclined to the horizontal, is adopted. Rotation about the vertical axis is used also to a limited extent for the production of castings of comparatively short lengths. With one exception, the author is not aware of any commercial application of rotation about the vertical axis for the production of long length castings in metal. The exception is a process known as the Billand Process, proposed by a German inventor for the production of long lengths of standard straight socket pipes. From experience the general rule would appear to be that spinning about the vertical axis which should be adopted for the production of those cylindrical castings in the radial thickness is exceptionally great in comparison with the length, e. g., wheels, locomotive piston heads, gear wheel blanks, thick section annular bushings and ingots. As a matter of fact, the method of rotation about the vertical axis is adopted in the commercial process for the manufacture of bronze worm wheels, steel wheels and similar castings. Rotation about an axis steeply inclined to the horizontal plane has been practised for the production of short length piston ring drums by the Ford Company of America. There does not appear to be any particular advantage in this method of spinning. A lower speed of rotation can be used in this case than in the case of the vertical axis; but this has to be set off against increased complexity in the machine design. In the two principal commercial processes for the production of pipes, a comparatively slight inclination of the axis of rotation to the horizontal has been adopted.

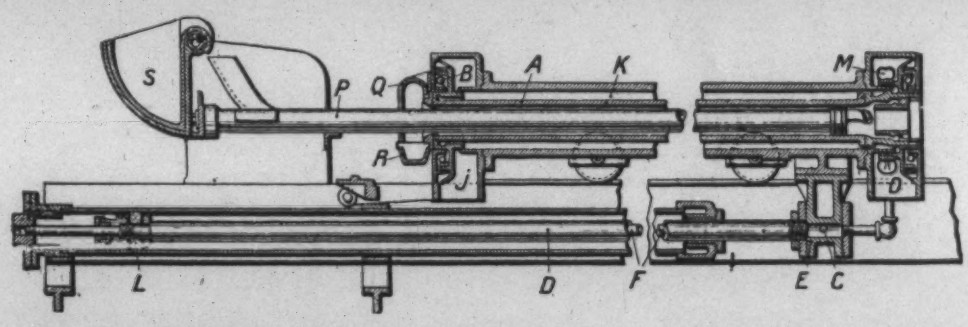


Fig. 14. Diagram showing arrangement of de Lavaud centrifugal casting machine.

(b) **The Method of Pouring:** In pouring a quantity of liquid into a rotating mold, no matter in what fashion providing the liquid remains liquid, it will eventually become evenly distributed over the surface of the mold, and assume a condition of equilibrium in which, in the case of spinning about the horizontal axis the inside surface is truly cylindrical. In the case of liquid metal which is only liquid for a short period of time, before it becomes finally solid, and moreover, during this period is increasing in viscosity at a rapid rate, the time available for the liquid metal to take up a condition of equilibrium over the whole surface of the mold is extremely limited. For the production of castings uniform in bore and thickness, it is necessary that the molten metal shall have sufficient time to distribute itself evenly, or some method of pouring adopted in which this time element is rendered of less importance in determining the even distribution of the metal. The method of introducing the molten metal into the rotating mold is the principal feature which differentiates the various systems of centrifugal casting. In the majority of systems where it is required to produce castings to close limits of dimensional accuracy, and particularly where metal molds are used, the method of pouring is the most vital and important feature of the process. Where the limits of accuracy are not so close and where the castings are of short lengths and comparatively bulky, the method of pouring is not nearly of such vital importance.

The earliest method of introducing molten metal into molds rotating about the horizontal axis was the use of some form of a bent funnel. Such a bent funnel suitably mounted, projecting into the die parallel to the axis of rotation allows the molten metal poured from an ordinary ladle to be directed onto the surface of the mold in a continuous stream. The even distribution of the whole liquid metal over the surface of the mold is acquired by the movement of the liquid metal over the surface of the mold in a direction parallel to the axis of rotation. This movement is brought about purely by the forces originating from the rotation of the liquid metal itself. The magnitude of these forces and consequently the rapidity with which these movements are brought about and completed, depends upon the rapidity with which the molten metal acquires rotational velocity in the first instance. The time available while the metal remains liquid for rotational velocity to be acquired and for uniform longitudinal distribution to take place, is so short that in practice this method of pouring is only successful when applied to the production of short length castings having a large radial thickness.

With the object of reducing the length of time required for the molten metal to distribute itself evenly over the whole length of the mold, the obvious method of pouring at several points or over the whole length of the mold simultaneously, constitutes the next development. In this manner, the distribution of the metal over the length of the mold parallel to the axis of rotation becomes more or less independent of the forces due to the rotation of the liquid metal. The apparatus used to effect such distribution takes a variety of forms and has been developed along various lines by different inventors The simplest form is a tilting trough of cylindrical cross section in which a portion of the cylinder wall is cut away in such a manner as to form a horizontal weir edge of approximately the length of the casting to be produced. This trough is mounted in such a manner as to enable it to be tilted or partially rotated about its longitudinal axis, and is either large enough in itself to hold sufficient metal for the production of the casting, or is attached to some external reservoir containing molten metal.

From the early days of centrifugal casting, it has been

recognized that, for the production of long castings of even thickness, the introduction of the molten metal must be effectively controlled. It is apparent from the early patents—and experiment confirms the fact—that the introduction of molten metal in a long flat continuous stream of approximately the same length as the casting is difficult to control from the point of view of the ultimate uniform even thickness of the pipe.

With the object of acquiring still greater control over the pouring operation, the use of a stream of metal of comparatively narrow width combined with means for applying this stream to the surface of the mold was contemplated by various inventors. The methods adopted, in almost every case, utilize the means of relative longitudinal movement between the mold and the metal stream itself. This will be understood readily from the description of three typical cases. In 1891, Lane designed a machine in which the stream of metal was allowed to issue from the end of a tubular spout and at the same time the mold was continuously withdrawn over the spout. The effect of this relative longitudinal movement between the mold and pourer spout is such that providing the movements are properly synchronized, the stream of metal is continuously deposited over the whole surface of the rotating mold.

Briede in Germany in 1912 designed a machine embodying this relative longitudinal movement between the pourer spout and the mold. These systems of relative longitudinal movement between the mold and a narrow stream of molten metal have culminated in the modern system, invented by Sensaud de Lavaud and known as the de Lavaud system. This is the system extensively adopted for the production of cast iron pipe. A diagrammatic illustration of the de Lavaud machine as used at the Stanton Company is given in Fig. 14. The mold while rotating is moved longitudinally in a direction away from the end of the pourer. It can be imagined readily that if this longitudinal movement is correctly synchronized with the rotational speed of the mold the metal issuing from the end of the pourer will cover the whole of the surface of the mold. If in addition to this, provision is made for the molten metal to be delivered from the pourer at a uniform and controllable rate, then the casting will be of uniform and controllable thickness. The segmental shape of the tilting ladle is specially designed to supply uniform quantities of metal to the pourer trough.

The Billand process which has been referred to previously operates on a similar principle, but in this case the whole operation is conducted with the mold rotating about the vertical axis.

The rate of solidification of the molten metal is an important factor in determining the degree and method of pouring control adopted. Where the period of solidification can be prolonged either by the use of heated molds or by the use of mold of low conductivity materials such as sand, the methods of pouring can be and are modified. Under such conditions, the allowable time limit for the solidification of the molten metal is increased thus increasing the time available for the molten metal to distribute itself evenly under the longitudinal forces due to its rotation. Cammen has proposed the use of metal molds operating at comparatively high temperatures, in which case the simplest forms of pouring arrangements presumably can be adopted.

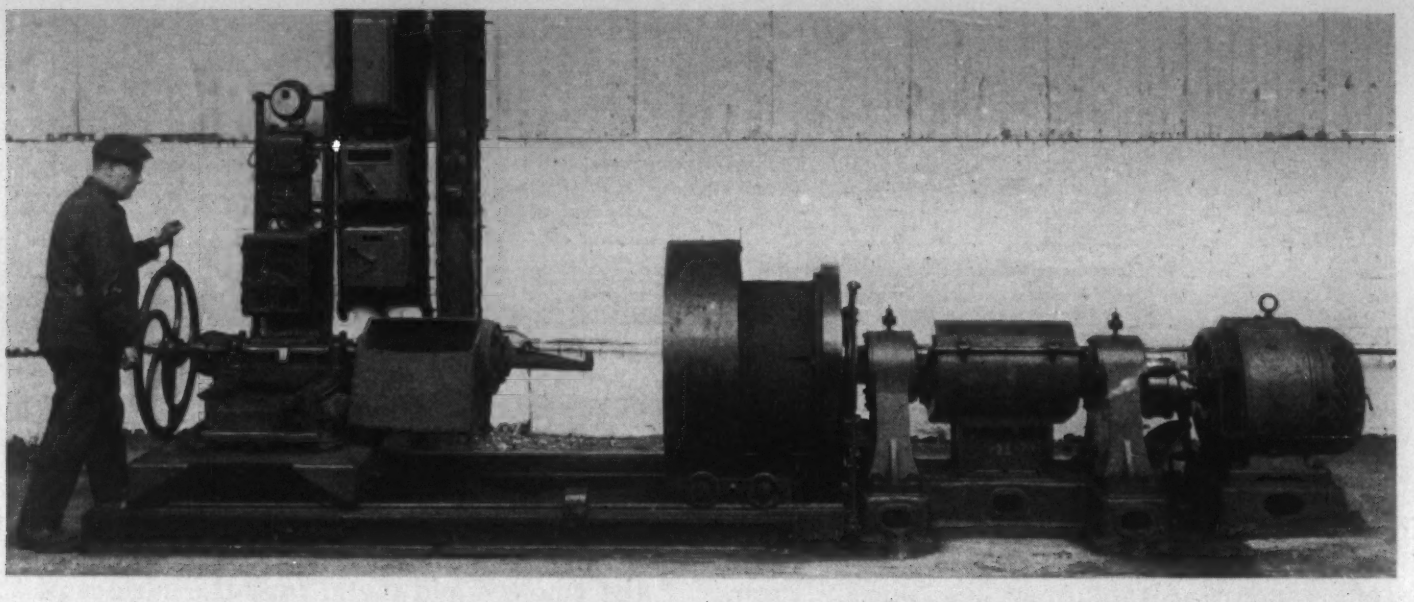


Fig. 15. Centrifugal casting machine for the production of cylinder liners and general centrifugal castings. (Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield, England.)

The sand spun processes as they are now called utilize sand molds and the methods of pouring adopted in conjunction with such molds take advantage of the longer period of solidification under these conditions.

The Moore sand spun process developed by W. D. Moore of the American Cast Iron Pipe Company and the Sand-Spun Patents Corporation is specially interesting and has been adopted extensively in various countries. In this process, the sand mold is revolved about an axis slightly inclined to the horizontal. The molten metal is introduced into the mold and during the pouring in of the metal the mold is slowly lowered so that it is perfectly horizontal at the conclusion of the pouring operation. Rotation of the mold is continued throughout this operation, at a speed sufficient to distribute the metal over the mold surface. When the horizontal position is reached, the speed of rotation is raised and retained until the casting has solidified. The carefully designed mechanism of pouring allows of the complete distribution of the metal over the sand mold without that shock which would otherwise tend to disintegrate the mold surface.

The Possenti process is another one in which a sand mold is adopted. In this case the pouring methods adopted, follow the simple type outlined previously.

(c) Form and Construction of the Molds. The use of sand molds produced more or less in the ordinary manner, has been resorted to since the earliest date of

the art of centrifugal casting. In the centrifugal casting of non-ferrous alloys, sand molds have been consistently adopted. One of the principal reasons for the use of sand molds is their low initial cost, a factor of vital importance where the total number of castings would not justify the cost of a metal mold. In the case of the production of cast iron castings, the use of sand molds presents one method of avoiding trouble due to the formation of chilled hard white iron surfaces. The centrifugal process lends itself admirably to the use of metal molds and in some of the principal processes in commercial operation, such metal molds are used. In the de Lavaud process for the production of cast iron pipe, an alloy steel mold adapted for water cooling is used. The principal processes operating in the production of general centrifugal castings such as piston ring drums and cylinder liners, molds of either cast iron or steel are employed. The effects of water cooling as practised in the de Lavaud process definitely necessitate the annealing of the castings to eliminate any trace of surface hardness and, furthermore, this treatment plays a great part in developing the strength properties of the castings.

In those processes operating with metal molds on the production of general castings, no water cooling is adopted. In practice, the molds attain suitable temperature and heat conditions to produce castings definitely free from chill. The credit for production of centrifugal castings in gray machinable cast iron free from chill on a commercial basis utilizing hot metal molds is to be ascribed to Stokes Castings, Limited, Mansfield. Cammen in America has proposed the use of hot metal molds. Cammen recommends mold temperature of the order of 750° to 1200° C. proportional to the thickness of the casting—the thinner the casting the higher the temperature. His primary object appears to be not so much that of eliminating the presence of chill as that of securing even distribution of the molten metal in long length molds. According to Cammen, the primary object of the mold should be to conserve the heat of the molten metal and with this view, the author is in direct opposition. The mold should be regarded primarily as a means for absorbing or dissipating the heat of the molten metal. The molds should be designed in such a manner that the heat absorbed from the casting is absorbed at such a rate that the rate of cooling of the metal through the critical range of temperature is not sufficiently quick to prevent the formation of the graphite. If these conditions can be obtained, then the castings will be free from chill.

Experience has definitely shown that these conditions can be obtained using metal molds either water cooled or air cooled for any given composition of cast iron within the limits of the ordinary grades of iron used in foundry practice. Furthermore a much lower temperature than that recommended by Cammen can be utilized to prevent the formation of chill, and gray machinable castings are produced under conditions where the inner surface temperature of the mold does not exceed 500° C. In the case of castings 4″ diameter by $^3/_8$″ thick, castings are produced daily at the rate of 15 per hour over a period of 8 hours without the above maximum temperature being exceeded. In no case has any annealing been necessary and all the castings are soft gray and readily machinable, the silicon content of the iron used, not exceeding 2.20%.

An illustration of the type of machine in use for the production of general castings embodying the design and principles in use at the Sheepbridge Stokes Centrifugal Castings Company, Limited, Chesterfield, England, is illustrated in Fig. 15. A typical example of the layout of a general centrifugal casting foundry is shown in Fig. 16.

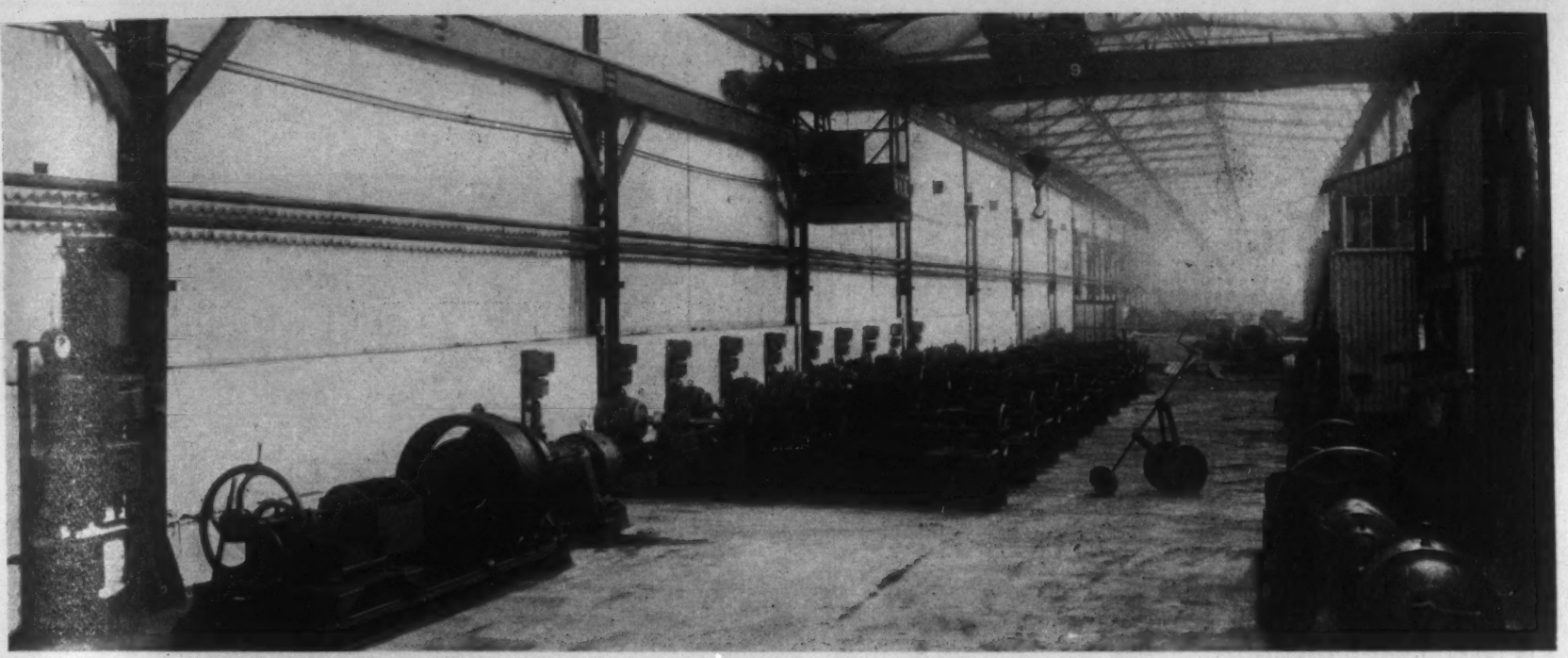


Fig. 16. **View showing typical layout of a centrifugal casting plant for the production of general centrifugal castings.**

Note: Cammen's recommendations were for steel while Hurst is speaking of cast iron. J. T. MacKenzie

◆ ◆ ◆

Lead-Zinc Flotation at Midvale, Utah

Concentrating practice at the Midvale plant of the U. S. Smelting, Refining and Mining Company is described in Information Circular 6492, "Milling Methods at the Midvale Concentrator of the U. S. Smelting, Refining and Mining Co., Midvale, Utah." Copies of the circular can be obtained free from the United States Bureau of Mines, Department of Commerce, Washington, D. C.

METAL FOIL Applications

BY R. P. STRANAHAN*

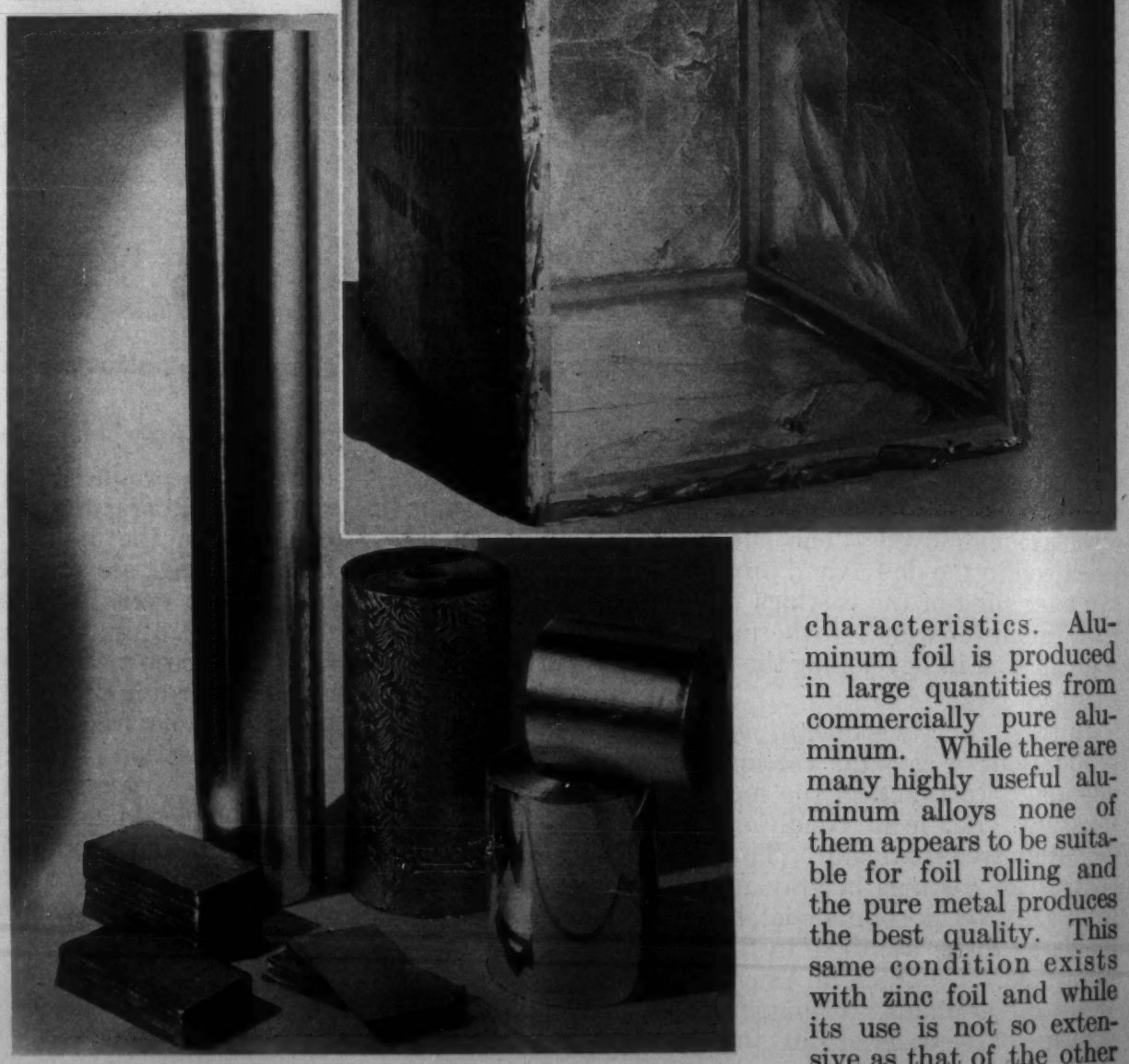
WHILE the foil industry is one which enjoys a wide and highly diversified market, it is at the same time one about which the public knows relatively little. This latter fact may be accounted for partly by the lack of literature on foil rolling, partly because of the small number of producers and also because foil, as such, is not an item that is sold at retail, it being, however, unconsciously associated with many hundreds of articles as a part of the package or wrapping.

Foil may be considered as any rolled metal lighter than sheet metal and heavier than metal leaf. There is no well defined line of demarcation between sheet metal and foil but this is usually considered as .005″ and anything heavier than this thickness can be called sheet metal, while anything lighter may be defined as foil with the exception of leaf. There is no conflict however between leaf and foil as the lightest foil rolled commercially is .0002″ thick—whereas metal leaf is usually .00002″ or thinner, about one-tenth the thickness of the thinnest foil.

The popular term "tinfoil" is something of a misnomer, as it is usually applied to foil in all forms whereas pure tin foil represents only a small part of the total production. Foil is rolled from tin, lead, alloys of tin and lead, zinc and aluminum. Tin and lead were the first metals used for this purpose and thin sheets of foil were beaten out by hand. The product obtained in this way is hardly comparable with the highly specialized foils manufactured to-day because of their non-uniformity of gage and lack of attractive appearance. In some parts of China this method is still employed and a part of the tea exported from China is still shipped in chests lined with the thin lead sheets which have been pounded out by hand labor.

The earliest mills were not capable of producing extremely light foils and neither was there a particular demand for sheets lighter than about .001″ in thickness, so for a number of years production consisted of tin and lead foil in relatively heavy gages. Later it was found that by proper alloying of small amounts of lead and antimony with tin it was possible to produce a material which could be rolled considerably lighter than the pure metal and by this means it has been possible to produce to-day a foil consisting of approximately 83% tin, 15% lead and 2% antimony capable of being rolled down to a thickness of .00022″, something less than a quarter of one-thousandth.

There are many other alloys of these metals used in foil manufacture and as each one has very definite characteristics, it will be used in connection with articles whose packages required those particular characteristics. Aluminum foil is produced in large quantities from commercially pure aluminum. While there are many highly useful aluminum alloys none of them appears to be suitable for foil rolling and the pure metal produces the best quality. This same condition exists with zinc foil and while its use is not so extensive as that of the other metals an extremely satisfactory sheet of foil can be produced from pure zinc.



Chest lined with aluminum foil (courtesy Thos. J. Lipton, Inc.) and group of foil products supplied to the trade.

Little need be said about the actual manufacture or rolling of foil itself as the process is similar to strip rolling of other metals. Rolling slabs of suitable metals and alloys are carefully prepared and these in turn are reduced through a series of rough or breakdown mills to a gage suitable for further reduction in a foil mill. At

* Reynolds Metals Co.

this point the operation becomes a highly specialized one and the ultimate product depends upon the skill—it may almost be called the art—of the roller and the condition and adjustment of the mill.

The foil mill is necessarily a precision machine and is constructed as such. Special attention must be given to bearings and their lubrication; rolls must be accurately ground and polished, and the lubrication of the foil itself as it passes through the rolls must be correct in order to secure proper reductions. Large reductions are obtained in the rolling of lead and tin foils and their alloys and relatively few passes are required to effect reduction to foil gages. Because their physical characteristics are different from those of tin and lead, zinc and aluminum require a greater amount of working and more mill passes are required than for the softer metals. After the last finishing pass the foil is wound on a core or reel and it is then ready for delivery to some other department for further processing.

NOW that the football season is at its height, one notes with amusement that newspaper photographers like to take pictures of the giant and midget of each team. This thought comes to mind in connection with this number of METALS & ALLOYS which includes—purely by coincidence—the article by Mr. Huston on page 209, on producing huge parts by welding thick plates, as well as this article on foils. True, as Mr. Stranahan points out, "leaf" is about one-tenth the thickness of the thinnest foil; but—"why bring that up?"

Foils for certain uses are supplied unmounted in either sheet or spool form but a far greater tonnage is supplied in some composite form where the foil is combined with paper. The foil itself may be in its natural finish or it may be colored red, green, gold, etc. It may have either a plain or embossed surface. The foil surface may require a certain amount of printing on it or it may be supplied unprinted. Since many different thicknesses of foil are manufactured it becomes apparent at once that it is possible to produce many thousands of specifications, no two of which are alike, by simply varying the kind of metal used, the color, the embossing design, the paper to which the foil is mounted, or the foil thickness.

A foil plant therefore is equipped with departments for laminating foil to paper, for embossing, coloring and printing. In the laminating or combining of foil and paper, wax is used as the adhesive on certain grades and on others the foil is solidly mounted to paper with glue. There are other requirements in which very narrow glue lines are used to adhere the paper to the foil. Embossing is done by passing a continuous roll of foil between engraved rollers, the design engraved on the roll being reproduced on the foil. Colored foils are produced by coating the foil surface with transparent lacquers which produce the proper color and at the same time preserve the sheen of the foil surface. Foil is printed by both letterpress and offset methods, and because of the luster of the metallic surface unusual and striking effects may be obtained. A foil surface is non-absorbent and printing inks therefore cannot dry as they do when printing is done on paper. This fact has led to the development of fast drying inks for use on foil

Representative products on which foil is used as a wrapping or packaging material.

and a printing technique peculiar to the foil industry.

The uses of foil may be divided into several major groups, first and most important being that of utility and decoration; second, the purely decorative field; third, the technical uses; and fourth a miscellaneous group.

In the first group, foil is used because of its preservative value, and the protection it affords against air, moisture and sunlight. No package can be considered as air tight unless the wrapper or cover is sealed and, where air tight protection is desirable foils having heat sealing paper backings are used. In the wrapping or packing operation the article is wrapped in such a foil and sealed by machine so that the air tightness of the package is maintained. There are some products which should be protected from air and moisture, and others which should retain a certain approximate moisture content, but which are kept in better condition if the package is not air tight.

Such articles are wrapped in a plain or paper backed foil but the wrapper is not sealed and a very small amount of air can pass from the inside to the outside of the package through the fold in the wrap. As the foil itself is impervious to air this small amount of "ventilation" is sufficient to preserve the goods in first class condition for long periods of time. Aside from the protection the foil affords, it also serves as a decorative wrap, since the foil may have either a flashy or delicate color, and it may be embossed with one of the many designs available. Private embossing designs are used on some packages, where it is desired to emphasize a particular decorative scheme or a well-known trade mark.

This group of products includes cigarettes and tobaccos which are wrapped principally in lead-tin alloy or in lead foil; the various brands of cheese on which pure tin foil is used; such items as candy bars and chocolate bars, yeast cakes, chewing gum, films, tea, etc., where a mounted or unmounted aluminum foil is generally used. It is well to mention at this point that due to the wide variation in specific gravity of tin, lead and aluminum the "yield" in square inches of surface per pound of metal is important. For example from a pound of tin, 7500 square inches of tin foil .0005″ thick are produced; from a pound of lead only 5000 square inches of lead foil .0005″ are produced; while from a pound of aluminum 20,500 square inches of aluminum foil .0005″ thick are rolled. It will thus be seen that the foil user is interested in knowing what his foil cost per thousand square inches is and will choose a kind of foil which costs him the least amount per unit of area and which will at the same time answer his requirements. With variable metal market prices there are corresponding variations in foil prices and these fluctuations are sometimes wide enough to influence the choice of foil for a given use.

In the purely decorative field aluminum foil is used almost exclusively. It is usually mounted solidly to paper with glue or similar adhesive and then used as a cover stock for fancy boxes or by the printer for de luxe folders, displays or signs. Because of the present vogue for dull gold and silver finishes, these metal surfaced papers are widely used as they blend well with modern decorative designs. Foil surfaced board is used in making folding cartons and unmounted foils are used in window display work and at Christmas time in the form of the familiar "tinsel."

Under the classification of technical uses the paper condenser or capacitor consumes the largest tonnage. The condenser is, of course, a necessary part of every radio set, telephone and automobile ignition system, and due to its design the foil is never visible, although it is one of the important parts. Most people therefore are unaware that foil plays such an important part in things which have become so commonplace.

The condenser foils are the lightest foils rolled and as the requirements are very exacting extremely careful inspection is necessary throughout the entire manufacturing operation in order to produce suitable material.

Foil is also an essential material in the electrotype industry where a lead-tin alloy is used as a solder between the shell or face of the electrotype and the backing metal. After the shell is made by electrodeposition it is laid on a horizontal surface face downward and sheets of electrotyper's foil are placed over it. By application of heat the reverse side of the shell is "tinned" and as the backing metal is poured over the shell a firm bond is made between the shell and backing material. Lead foils are also used extensively in cable construction and large tonnages are consumed in the manufacture of metallic packings for steam lines.

In the miscellaneous group there are several interesting applications, not the least important being the foil used as a liner for bottle caps or crowns. Millions of small foil discs are used every year on the inside of the caps of tooth paste tubes, shaving cream tubes and mineral water bottles, all for the purpose of insuring the product reaching the consumer in first class condition. Foil is used in the manufacture of window letters and as the base material for metal seals such as are used on cosmetic jars, perfume bottles and candy boxes. All of the leading brands of ginger ale and grape juice have a strip of foil around the neck and cap of the bottle in order to keep the mouth of the bottle clean. There are many holiday and seasonal novelties made from foil by a steadily increasing list of manufacturers.

A new and potentially large field for aluminum foil is developing in which this material is used as thermal insulation. Research has shown that a highly polished aluminum foil will reflect about 95% of the heat waves that fall on its surface and also that it has a radiating factor of emissivity of about 5% of that of a black body. By taking these characteristics into account an insulation made up of successive layers of aluminum foil from $^1/_4$ to $^1/_2$ inch apart will show an efficiency equal to that of the commercial insulations in use today. The principal advantage of a foil insulating material is its light weight, since a cubic foot weighs only a few ounces compared with several pounds per cubic foot for the other types of insulation. It is of course fireproof and when properly constructed is not subject to moisture damage, an important fact in low temperature insulation work. Further research will develop the most economical methods of employing foil for this purpose and from the viewpoint of the foil industry such developments should indeed be interesting.

◆ ◆ ◆

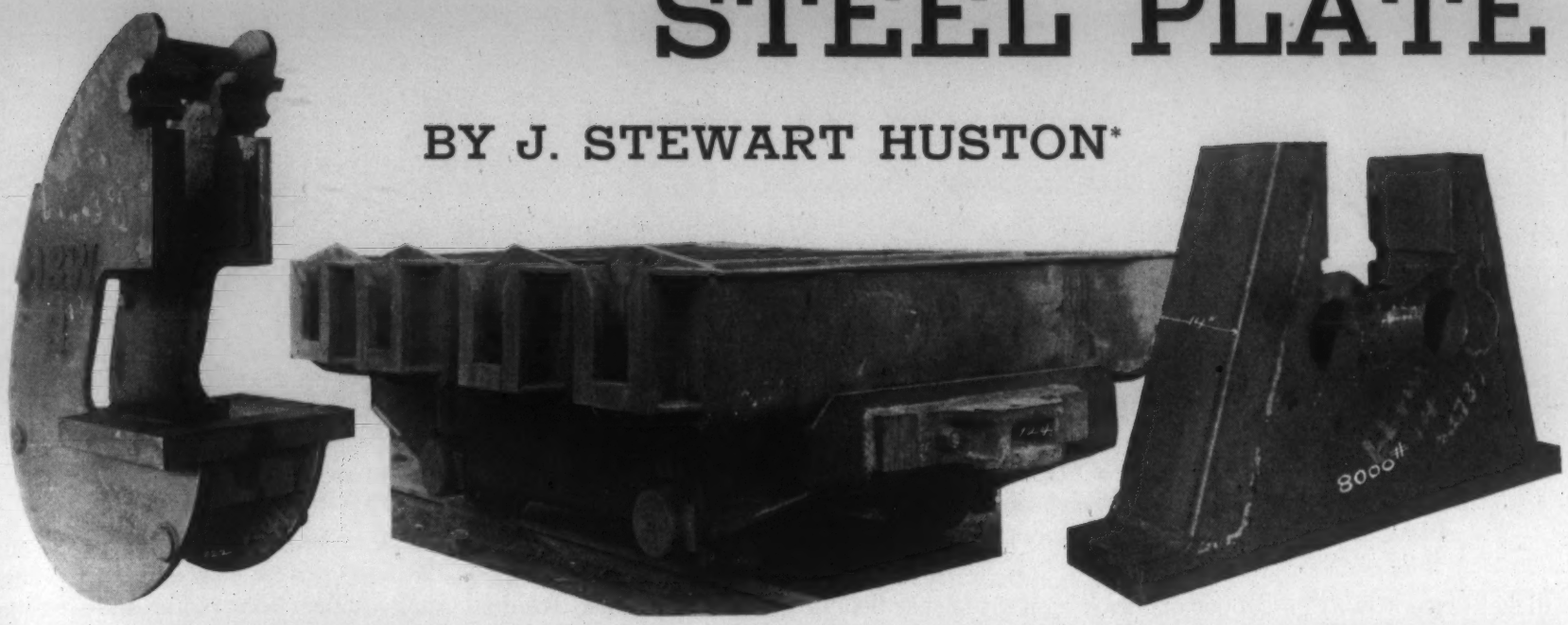
STANDARD SAMPLE

The U. S. Bureau of Standards has prepared a Standard Sample of 18–8 Cr–Ni (KA2S) Steel of the following composition: carbon .060, manganese .554, phosphorus .010, sulphur .012, silicon .759, copper .056, nickel 8.44, chromium 17.54, vanadium .044. This Standard is No. 101 in the series and costs $3.00 per sample of 150 grams. The sample may be paid for in advance with the order or be sent parcel post C. O. D. in the United States and its possessions. All foreign shipments require prepayment, together with 20 cents additional postage.

A complete list of standard samples, analyses, fees, etc., are given in Bureau of Standards Supplement to Circular No. 25, which can be obtained free of charge upon application to the Bureau of Standards, Washington, D. C.

Securing Quality in STEEL PLATE

BY J. STEWART HUSTON*



LEFT—All Welded Steel Inclinable 30 ton Press Frame. Weight 2690 lbs. with welded base. Using Heavy Plate. . . CENTER—Charging Boxes and Charging Car All Welded from Steel Plate. Weight of boxes 1200 lbs. each; weight of car 3170 lbs. each. . . .RIGHT—Bending Roll Housing Gas Cut from 14″ Plate.

LIKE other lines of manufacture, the production of heavy plate of good quality, primarily requires high grade materials with which to work.

These must be supplemented with intelligent care in the different steps of the process, from the time the various steel making ingredients are inspected as they are received in the stock yard until the finished article is loaded for shipment to the customer.

The writer is connected with one of the largest steel manufacturers whose output is exclusively plate and plate products. While this manufacturer rolls various thicknesses of plate and is known to stress quality rather than tonnage, they have learned that quality in heavy plate necessitates more than the usual attention to details.

ORIGINATED 140 YEARS AGO

This organization has had an interesting history, covering a period of over 120 years in its present location, and an experience of almost 140 years, since 1793, when its founder established a small slitting mill run by water power on the Buck Run, about four miles south of Coatesville. In 1820 the proprietor, Dr. Charles Lukens, formerly a practicing physician who had considerable foresight, succeeded in introducing charcoal iron plate for use in the fabrication of steam boilers, copper having previously been used for that purpose. So far as is known, this was the first instance where any ferrous metal plate was manufactured for steam boilers in America.

Dr. Lukens' widow succeeded to the business and, in writing of her early business experiences, ascribed her rather phenomenal success to an earned reputation for quality and fair dealing, which brought in as much business as the mill could handle.

It is important to consider this high standard as the outstanding legacy of the present organization, all vestiges of the original plant having long ago given way to the march of progress, and charcoal iron having for many years disappeared from any list of its products.

* Secretary and Plant Metallurgist, Lukens Steel Company.

THE WORLD'S LARGEST PLATE MILL

During the recent war, a four high plate mill was installed, with rolls 206″ long, which enables this company to roll wider plates than can be made in any other mill, the next largest being a two high plate mill at the Witkowitz plant in Czecho-Slovakia, with rolls $4^3/_4$ meters, or 187 inches wide. This 206″ mill with later improvements, enables this company to produce plates in any width up to 202″. It has rolled plates as thick as 25″ and has handled ingots as heavy as 89,000 lbs.

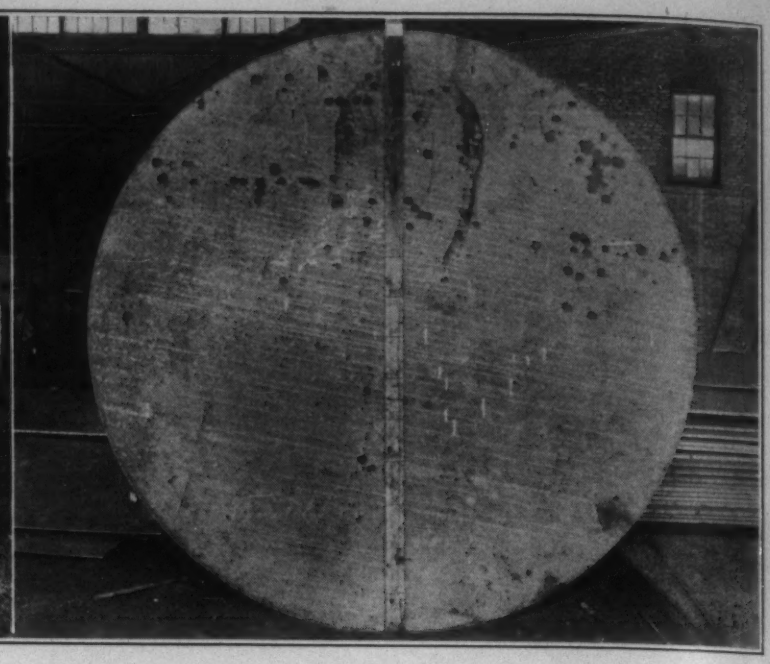
This company is equipped with normalizing and annealing furnaces, some of which have recording pyrometers, where a large variety of annealing and heat treating is carefully done.

RAW MATERIALS

Heavy plate may be divided into two classifications, which will be dealt with separately, (1) straight carbon and lower grade alloy steels, which can be made in the open hearth furnace, and (2) high grade alloys, made usually in the electric furnace, including alloy clad steels, where the "cladding" cannot be made in the open hearth.

In the making of open hearth steel for quality plates, one of the primary factors to consider is the selection of the proper raw materials. Steel scrap is purchased under rigid specifications. The best quality is clean plate scrap cut from the sides and ends of the company's own plates, where the analysis is known to be low in sulphur and phosphorus. The acid furnace has to use this type of scrap because the chances of eliminating sulphur and phosphorus are naturally much smaller there than in the basic furnace. In spite of this, however, the acid process, due to the affinity of acid slag for iron oxide, produces steel which is usually more free from objectionable non-metallic impurities, and is, from this standpoint, superior to basic steel for firebox purposes. If the scrap is too light it will result not only in objectionably long and costly charging and melting time, but usually in an increased amount of undesirable dirt, due to the greater oxidation of the charge. Scrap should be clean (that is, free from adhering slag or heavy rust), and should contain a minimum content of alloys, the most objectionable being copper and

Front and Side View of Heavy Plate Fly Wheel Circles. 121″ × 8¾″.



Circular Plate for Fly Wheel 181″ × 5⁵/₁₆″. Weight 43,000 lbs.

nickel (except where a copper or nickel content is specified in the finished product) aluminum, tin, zinc and lead. Chromium will oxidize to a refractory powder, which is extremely difficult to eliminate. Tin, zinc and lead are hard on the basic furnace bottom, although the oxides of tin and zinc will volatilize freely, and a large portion should be carried off in the stack gases.

Pig iron at this plant is purchased in the cast form and charged cold. For the acid furnace it should be low in phosphorus and sulphur (preferably under 0.05 P and 0.03 S). Manganese in acid pig iron does not have to be much over 1% and silicon is usually around 2%. A high silicon content tends to cut down the losses due to oxidation of the iron and consequent harm to the acid lining.

Pig iron for the basic furnace should be low in sulphur (under 0.05), but phosphorus is usually much higher (under 0.50). Phosphorus being a deoxidizer will, it is believed, help to cut down oxidation losses of the iron, and is readily eliminated by the basic slag. In order to obtain the best melting, it has been found that reasonably high manganese and silicon contents are desirable, the ideal combination being around 1.75 manganese and 1.30 silicon. This has the triple advantage of (1) shortening the melting time, (2) causing the heat to melt high in carbon, thereby eliminating costly pig iron additions with lengthened furnace time and (3) creating better quality of product, not only more free from dirt inclusions, but with cleaner surface in the rolled plate.

MELTING

The condition of the furnace has a bearing on the quality of the product. If a furnace is having a run of bottom trouble this will tend to throw a large number of inclusions into the steel. It is often desirable to run a furnace for a continuous time on heats of similar analyses, so as not to contaminate steel of one special analysis with what has soaked into the furnace bottom from a previous heat of entirely different analysis.

Charging and steel making practices vary for different open hearth plants. Economic and other factors may create a set of ideal conditions for one plant, which are totally unsuited to another plant.

There can be no doubt that the quality of a heat of steel depends primarily on what has happened to it in the furnace.

QUALITY

Among the factors to be considered for quality steel in the furnace bath are slag composition, slag viscosity, working temperature, residual manganese, iron oxide and carbon contents of the steel, all of these being inter-related. Although it is difficult to save a poorly made heat of steel by proper treatment in the ladle, it is comparatively easy to ruin a heat of excellent quality by improper ladle treatment. High quality open hearth steel plate may be made either "open" or "killed."

OPEN STEEL

"Open" steel which is also known as "effervescing" or "rimmed" steel, is used where high grade boiler or fire box plates are wanted from medium carbon steel. This steel has been considered superior to ordinary "killed" or deoxidized steel in withstanding the "breathing" effect of a pressure vessel which is subjected to pulsation stresses. It is comparatively free from the "piped," or laminated condition frequently found in killed steel; usually has a surface freer from objectionable defects and will not act as "dry" as killed steel in a forge or butt welding operation. To make good rimming steel it should have just the proper amount of deoxidizers added to it in the furnace and ladle to give the metal a good, uniform evolution of gas while it is cooling in the molds. This will insure a solid outer rim of metal from 1½″ to 3″ thick (depending on the size and shape of the mold) around the ingot before the center solidifies. If too much deoxidizer is added, the outer portion of the ingot will be honeycombed with small gas cavities, and semi-killed steel will result. It is difficult to obtain a good direct rolled plate surface from semi-killed steel.

Similar conditions apply to steel poured at too high a temperature, particularly in acid steel.

When an insufficient amount of deoxidizer is added the steel has the tendency to be "wild" or to splash violently during pouring. This can be corrected by adding aluminum during the pouring, but usually not before harm has been done to the surface of the ingot.

"Open" steel for quality plate is usually "bottom poured" through a "fountain" or "center runner," there being anywhere from two to twenty-four ingots poured at the same time. The advantages of bottom pouring are greater freedom from splashing and a slow rate of rise of the steel in the molds.

Ingots that have bad splashes on their sides very frequently roll into plates with rough "scabby" surfaces. Where the steel has been poured too rapidly there is a tendency to create skin blow holes, causing "scabs" and "seams" and surface cracking, causing "snakes."

Bottom poured "open" steel ingots can be direct rolled, that is, heated after removal from the open hearth pit, and rolled without any intermediate working direct into the finished plate. Top cast ingots, and bottom cast killed steel ingots, usually have to be double converted, that is, heated and slabbed and then, after chipping out the defects reheated and re-rolled into the finished product.

In bottom pouring, care should be used to insure clean runner connections, proper centering of the molds over the outlet bricks and slow opening of the ladle, so as to avoid too much splashing due to the pressure head of the steel in the ladle, until a pool of steel several inches high has been formed in the bottom of the molds.

"KILLED" STEEL

"Killed" steel is used where extreme freedom from segregation and uniform physical properties throughout the plate form part of the requirements.

It is used for most open hearth alloy steels.

Very large ingots, 30 and 40 inches thick, are usually made of killed steel. To get freedom from pipe, killed steel ingots are often cast with a hot top. The use of "big end up" molds also aids in the removal of pipe. The deoxidizers are more properly added in the ladle, although good results are obtained by killing in the mold.

POURING

"Killed" steel may be either top or bottom poured, the largest ingots being top poured and smaller ingots often bottom poured. Important features in obtaining a good surface are rate of rise of the steel in the mold and pouring temperature. The ideal rate of rise has been found to be between 10 and 12 inches per minute for both "open" and "killed" steel, the lower limit being more necessary for killed steel, where the metal has a greater tendency to crust over.

The ideal pouring temperature varies with the composition of the steel, from 2830° F. with 0.10–0.20 carbon, to 2790° F., with above 0.50 carbon. A heat which is to be bottom poured is rarely held in the ladle for a calculated temperature drop, although in some steels, both "open" and "killed," where the specifications call for extreme freedom from inclusions and where scavengers are added in the ladle, the ladle should be held a sufficient length of time to permit the scavengers to work.

With top poured steel the temperature of the steel as it leaves the furnace is observed with an optical pyrometer. The ladle is then held a sufficient time after removal from the stand below the furnace to permit the temperature to drop to the required point before opening the ladle. The rate of temperature drop depends on the design and size of the ladle and can be calculated easily after observing several heats. After opening the ladle on the first group, the fall in temperature becomes more gradual, probably due to the fact that the heat losses from conduction to the ladle have decreased to a minimum, and to the insulating action of the slag on top of the steel in the ladle.

SCAVENGERS

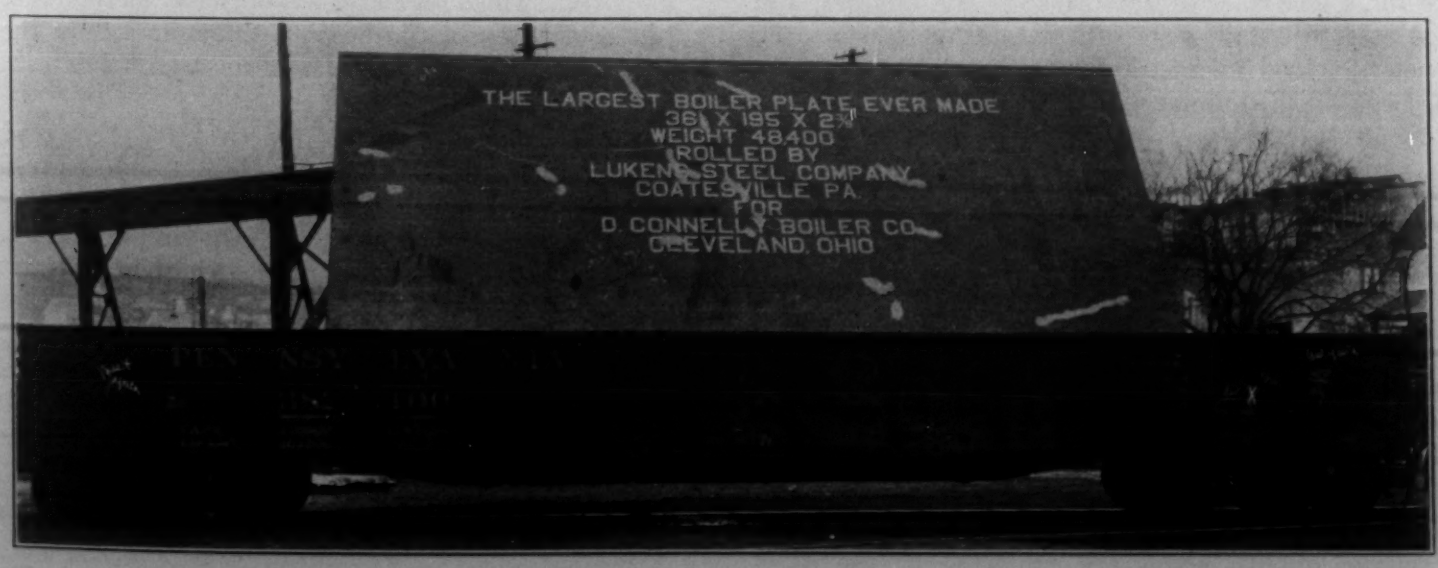
Scavengers as deoxidizers are added in the ladle and are selected so that their products of oxidation will easily flux out the non-metallic impurities. Ferro-manganese, ferro-silicon and ferro-carbon-titanium are all useful scavengers. An ideal scavenger, made to give an extremely fusible slag, with the non-metallic impurities in the ladle, has been developed by this company from a combination of these three.

MOLDS

Better rolled surface from killed steel ingots has been found with the use of vertically corrugated molds than with other types. The corrugations tend to support the ingot wall as it cools in a number of evenly spaced positions, causing a lessened amount of surface cracking. Mold condition has an important bearing on quality. Molds for both open and killed steel should be thoroughly cleaned and coated with a thin wash to prevent any sticking of the steel to the mold. They should not be used so soon after being stripped from a previous batch of ingots as to show temperature color, nor should they be used absolutely cold. The best temperature for a mold before use is that which will permit one to lay one's hand against the mold. A poor ingot surface, particularly in "open" steel, is sometimes due to unduly slow or rapid cooling from the wall of the mold, the rate of cooling being affected by the temperature of the mold wall before pouring.

HEATING

For both "open" and "killed" steel it has been found desirable, from a quality standpoint, to charge, as quickly as possible after the ingot freezes, into the mill heating furnace. This saves the heat in the interior of the ingot, shortens the heating time, helps to give a more uniformly heated ingot before rolling, and diminishes the percentage of "snakes." For special plates, it is desirable to see to it that there is no delay between stripping the mold from the ingot and charging the ingot into the heating furnace. A mold should not be stripped from an ingot until the ingot has entirely freed itself from the inside surface of the mold. The time taken for an ingot to free itself from its mold where the ordinary solid and one piece mold is used, varies from about 20 minutes for a 7" thick ingot to 5 hours for a 40" thick ingot. If an ingot is not to be immediately charged into the heating furnace, there are advantages in letting it cool slowly in the mold, but this is expensive as it lowers the life of the mold.



The Largest Boiler Plate Ever Made. 361″ × 195″ × 2¾″ weighing 48,400 lbs.

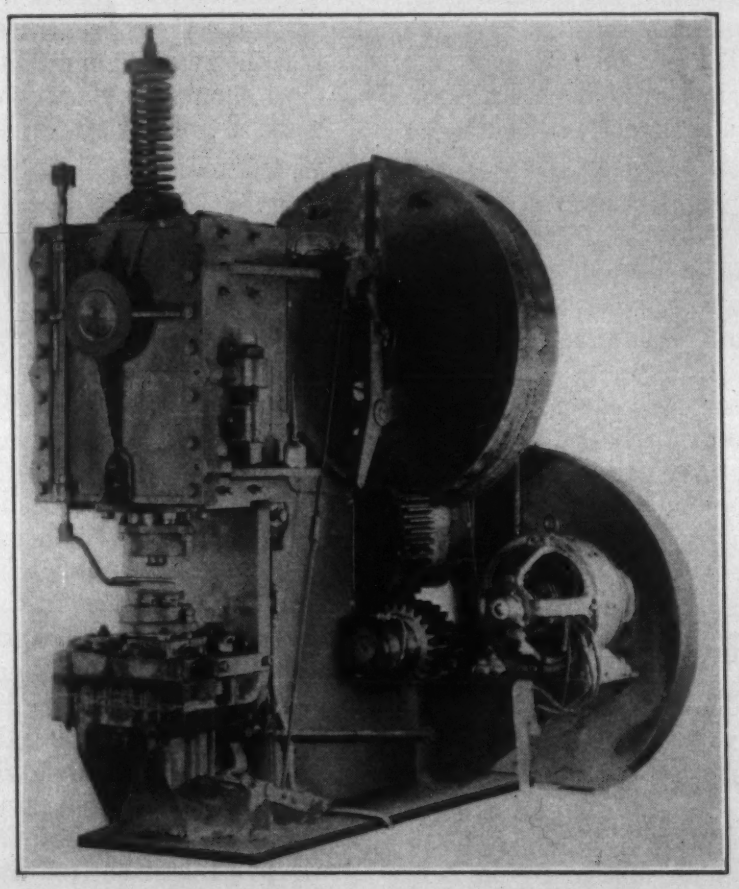
After the steel ingots are charged in the heating furnace, they should be thoroughly and evenly heated before rolling.

It has been found that a good heating practice is to carefully heat the ingot to 2000° F. and then soak it for ½ hour per inch of thickness before rolling. The heating temperature of medium carbon steel should never exceed 2300° F. and should be kept to an average of 2250° F. Care should be taken in charging and heating the ingot to see that the flame does not unduly waste away any particular portion of it, causing "hot spots" as it comes out of the furnace. These are very objectionable in "open" steel and in cases where the outer rim is comparatively thin will be the direct cause of "scabs," "pits" and "seams." "Washing" an ingot, that is, evenly wasting away the outer surface, is sometimes advantageous in removing splashes against the side of the ingot, but can only be permitted in cases where the outer rim is extremely thick. "Washing" is expensive in oxidation losses.

With clean, well made ingots, the ideal furnace atmosphere is a comparatively neutral one.

ROLLING

Ingots, after being taken out of the heating furnace, should not be given too heavy drafts to start with in the rolling mill. Light initial drafts will have a beneficial effect on the ingot, similar to a forging operation. Sometimes, in cases where there is a tendency toward side or end cracking, the ingot should be cornered, that is, rolled cornerwise rather than directly side or endwise in the first few passes through the mill. Scale from the heating furnace can be removed with salt thrown on the plate or, better yet, with light brush or burlap bags. This catches the cooling water from the mill and carries it between the rolls, causing an explosion when the water suddenly expands to steam while subjected to the pressure of the rolls and the temperature of the plate, and this explosion very effectively removes the cinder.



525 ton Washer Press, in which the housing, outboard bearing, the frame, gears and fly wheels were made of welded steel plate.

The best finishing temperature for quality carbon steel plate is, in the writer's opinion, between 1550° and 1300° F. This gives a more uniform grain structure and a nice color to the surface of the product, and is not too cold to obtain a smooth plate after it leaves the roller leveler. Good microstructure is obtained where the plate has been finished under pyrometric control.

SHEARING AND GAS CUTTING

Plates up to 1½" thick are cut to the required patterns by the ordinary plate shears. Over this thickness they are trimmed by the oxy-acetylene process. Thicknesses up to 25" can be cut by the oxy-acetylene machine accurately to pattern. The metal adjacent to the edges after the proper subsequent annealing shows good microstructure. One advantage of the gas cutting is that it clearly shows up any flaws in the interior of the metal.

INSPECTION

After rolling, quality plates are subjected to the most severe inspection to show up any surface or other defects. Before the plate is inspected by the customer's representative, it is most carefully gone over by the company's own staff. In the case of special locomotive firebox plates, the surface area is laid off into small squares and each square hammer tested by an experienced man for laminations and blisters. Small laminations, the size of a post card, have been discovered in this way.

ALLOYS

During the past three years a great deal of work has been done in developing the rolling of high grade alloy plates. The heating and working of this material has been under direct metallurgucal supervision, and records have been kept of the history of every alloy article as it passes in the different stages through the plant. Approximately 60 different grades of these alloys of varying analyses have been rolled to date. A card index is kept for quick reference of the most satisfactory method for heating, rolling, forming and heat treating each particular grade. A staff of trained observers is maintained, so that an experienced man is present during the heating or working of any alloy article. This, with the coöperation of the various rolling mill men and flangers, has resulted in much progress in this particular field. This same staff also superintends the annealing and heat treating of carbon steel and open hearth alloy plates.

NICKEL CLAD PLATES

One of the most recently developed products at this plant is nickel-clad steel. This consists of a plate of medium low carbon open hearth steel, to which pure nickel plate is bonded. The nickel ranges from 10% up, of the total plate thickness. Tests on this material have indicated very uniform thickness of the nickel coating.

The problem of welding the nickel to the steel by heating and rolling, without overheating or burning the nickel, is a delicate one. The process has, therefore, been placed under the supervision of the alloy staff, which regulates not only the method of charging, but every step of the heating and rolling. In the case of flanged heads of nickel clad steel this staff regulates the flanging temperatures.

Nickel clad steel makes practical the heavy plate construction jobs, where it is desirable to obtain corrosion resistance of the equipment and non-contamination of the product, at a cost considerably lower than that of pure nickel. It has been found to be superior both in yield point, ultimate tensile strength, elongation and reduction in area to the straight carbon steel without the nickel coating.

The writer is indebted to W. G. Humpton, Metallurgical Engineer, of the writer's company, for the following comparative tests of the nickel clad and plain steel rolled in two different gages, where the carbon steel came from the same open hearth melt.

This melt analyzed Carbon, 0.20; Manganese, 0.47; Phos., 0.018; Sul., 0.040.

Gage	Grade	Yield Point, lbs./in.²	Ult. Ten. Str., lbs./in.²	Elongation, % in 8″	Reduction in Area, %
1/2″	plain	36,500	60,300	30.0	54.4
1/2″	nickel clad	40,200	60,800	30.5	59.0
5/8″	plain	33,200	60,600	27.0	61.1
5/8″	nickel clad	40,300	62,200	30.5	63.0

A recent application of nickel-clad steel was in 8000 gallon steel tank cars, built by the General American Tank Car Corp. for the transportation of iron-free caustic soda. Plates used in this construction were 382″ × 91″ × 5/16″ and 382″ × 81 3/8″ × 7/16″, which illustrates the large sizes in which this material can be rolled.

Uses for nickel-clad steel also embrace large diameter piping, large tanks, large crystallizing trays and evaporating equipment, large hoppers, mixing and conveying equipment, pressure kettles, condenser shells, digesters, water heaters and stills. Nickel-clad steel can be flanged and dished into heads of all types.

LARGE PLATES

Along with the developments in alloy and nickel-clad steel plates there have been some interesting applications of heavy steel plates. A rectangular plate, 361″ × 195″ × 2 3/8″, weighing 47,400 lbs. was recently supplied for a boiler drum. A circular plate, 181″ diameter × 5 5/16″, weighing approximately 43,000 lbs., was made for an electrical equipment manufacturer for a fly wheel. A firebox plate, 360″ × 175 17/32″ × 2 3/8″, weighing 42,786 lbs., was shipped to a Canadian works, and another firebox plate, 300″ × 80″ × 4″, weighing 61,400 lbs., was exhibited at the A. R. A. Convention in Atlantic City in 1930. A plate 318 1/2″ × 178 3/16″ × 2 5/32″, weighing 37,250 lbs., of flange quality for forge welding, was recently sold to a forge welding shop, and a flanged head of special open hearth steel, 60″, inside diameter, × 5 1/8″, minimum thickness, was recently shipped to a manufacturer of welded oil cracking stills.

Column bases as large as 72″ × 128″ × 12″, and weighing 31,330 lbs., were made for the Bank of Manhattan Building, and as large as 132″ × 72″ × 20″, weighing 54,529 lbs., and 140″ × 98″ × 14 3/4″, with a weight of 57,340 lbs., for the Metropolitan Life Insurance Building, New York City.

Plates can be rolled in the 206″ mill large enough to make a one piece crown and side sheet for a locomotive. A recent plate of this type measured 236″ × 195 1/2″ × 3/8″.

WELDING

Recognizing the possibilities of the use of plate in welded construction, the writer's company has recently organized a division for this purpose.* This division has been developing a great many uses for welded plate to take the place of iron and steel castings; among the products are listed machinery parts, bed plates, gears, machine bases, fly wheels, charging boxes and charging box buggies for the steel plant, water cooled doors for furnaces and reduction gear cases. Plates of all gages are required. Recently in making the main housings for a shear, plates 96″ × 29″ × 25″ thick were used.

HEAVY PLATE SHOULD BE QUALITY PLATE

Heavy steel plate is used for jobs of unusual size and type, and when properly manufactured possesses that degree of quality which will permit its use on important work. It may be sheared, gas cut, formed, clad with nickel or welded.

Only where quality exists in heavy steel plates is it suitable for special applications. Hence, quality may be considered the vital factor in heavy plate.

* Lukenweld, Inc.

Metallurgical Lectures in Pittsburgh

A series of fifteen lectures on the basic principles of metallurgy are being given under the auspices of the Pittsburgh Chapter of the American Society for Steel Treating. The lectures will take place in the H. C. Frick Teacher Training School, each Tuesday evening at 8 p. m. The fee for the course is $10.00.

The lectures and lecturers as follows:

1. Introductory, General Principles of Physics and Chemistry as Applied to Metallurgy. C. H. Herty, Jr., U. S. Bureau of Mines.
2. Pyrometry and Fuels. E. G. Hill, Lukens Steel Co.
3. Refractories and Furnaces. J. Spotts McDowell, Harbison-Walker Refractories Co.
4. Manufacture of Iron and Steel. C. H. Herty, Jr., U. S. Bureau of Mines.
5. Metallurgical Terms, Crystallization and Metal Structures, S. L. Goodale, University of Pittsburgh.
6. Structures and Properties of Pure Metals, and Hot and Cold Working, S. L. Goodale, University of Pittsburgh.
7. Alloys, Their Structures and Properties, V. N. Krivobok, Carnegie Institute of Technology.
8. The Iron Carbon Diagram, Norman Woldman, Westinghouse Electric & Mfg. Co.
9. Plain Carbon Steels, Norman Woldman, Westinghouse Electric & Mfg. Co.
10. Heat Treating Operations. N. I. Stotz, Braeburn Steel Corp.
11. Mechanical Shaping of Metals. J. A. Succop, Heppenstall Co.
12. Alloy Steels (Except High Speed and Stainless). V. N. Krivobok, Carnegie Institute of Technology.
13. High Speed and Stainless Alloy Steels. J. P. Gill, Vanadium Alloys Steel Co.
14. Wrought Iron, Cast Iron and Cast Steel. Dr. James T. Aston, Carnegie Institute of Technology.
15. Physical Testing of Metals. R. L. Templin, Aluminum Company of America.

◆ ◆ ◆

The Nitralloy Corporation, of 230 Park Avenue, New York, N. Y., which owns and/or controls various patents for the process of nitriding, composition of alloy steels and cast irons, furnaces, etc., has been very active during recent months in developing a constructive and far reaching program to stimulate interest in and to expand the use of Nitralloy.

The Electric Furnace Company of Salem, Ohio, which holds a furnace license from The Nitralloy Corporation, and the Commercial Steel Treating Company, Detroit, Michigan, have joined with the Nitralloy Corporation in a program for the erection and operation of a demonstration nitriding center in the latter company's plant at Detroit. The plant is now ready for operation.

The furnace as installed is the latest design made by The Electric Furnace Company, It is of the electrically heated semi-continuous, horizontal type with three nitriding boxes provided with forced gas circulation. The size of the largest box is 60″ × 18″ × 18″, the two smaller boxes being 19 1/2″ × 18″ × 18″. The furnace is so designed that it will be possible to make runs on different time cycles in the two smaller boxes simultaneously and to accommodate a variety of sizes and shapes.

The following concerns are established and in operation as accredited nitriding agents of The Nitralloy Corporation:

Arrowhead Steel Products Co., Minneapolis, Minn.
Camden Forge Company, Camden, N. J.
The W. S. Biddle Company, Cleveland, Ohio.
Lakeside Steel Improvement Company, Cleveland, Ohio.
Lindberg Steel Treating Company, Chicago, Ill.
New England Metallurgical Corporation, South Boston, Mass.
Queen City Steel Treating Company, Cincinnati, Ohio.
Wesley Steel Treating Company, Milwaukee, Wis.

The following companies are licensed to produce Nitralloy steel and Nitralloy castings at the present time:

Steel
Bethlehem Steel Company, Bethlehem, Pa.
Crucible Steel Co. of America, New York City.
Firth-Sterling Steel Co., McKeesport, Pa.
Ludlum Steel Co., Watervliet, N. Y.
Vanadium-Alloys Steel Co., Pittsburgh, Pa.

Steel Castings
Duquesne Steel Foundry Co., Pittsburgh, Pa.
Electric Steel & Mfg. Co., Los Angeles, Cal.
Empire Steel Castings Co., Reading, Pa.
Milwaukee Steel Foundry Co., Milwaukee, Wis.
Warman Steel Castings Co., Los Angeles, Cal.
Massillon Steel Castings Co., Massillon, Ohio.

The Nitralloy Corporation has recently cancelled the license under which the Republic Steel Corporation of Massillon, Ohio, formerly operated.

The following companies are licensed to manufacture furnaces suitable for nitriding:

Leeds & Northrup, Philadelphia, Pa.
Electric Furnace Company, Salem, Ohio.

Testing DEEP DRAWING

BY H. W. GILLETT* with

THE FORMING of sheet metal by die-pressing and stamping, into a wide variety of useful articles, ranging from pill boxes to automobile bodies and fenders, is a rapidly advancing art. It is a very cheap method of fabrication in quantity production, though the presses and dies are decidedly expensive.

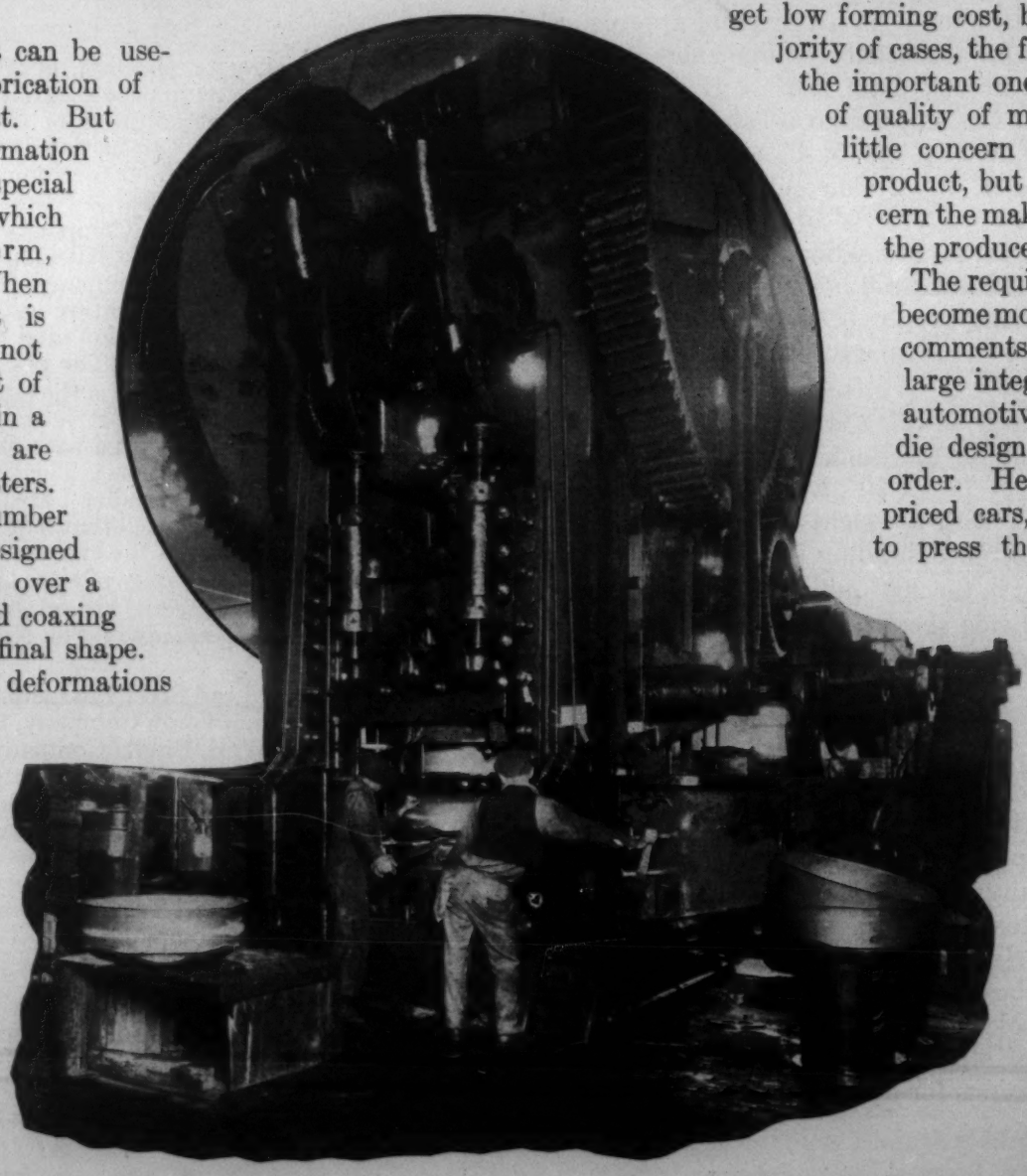
Metal hardens up on cold deformation, and will only withstand a definite amount of deformation without breaking. If the ability of the metal to stand local deformation is exceeded, it will fail at the over-deformed location. The deformation imposed may be a stretching in tension, or, as on the inside of a flange, it may be compression. When both types of deformation occur together, as they usually do, the stamped part may wrinkle and buckle. The metal may flow nicely without fracture or wrinkling, but the surface may become rough instead of drawing down smoothly. Thus there are several types of failure to produce the desired part of the desired dimensions and appearance.

Almost any sort of sheet can be usefully employed for the fabrication of some simple drawn object. But when extreme local deformation is required, material of special properties is needed, to which is applied the general term, "deep-drawing stock." When the design of the object is such that the sheet will not stand the brutal treatment of banging it into final form in a very few operations, there are two ways to mend matters. One is to increase the number of operations, using dies designed to spread the deformation over a wider area of the sheet, and coaxing it, little by little, into its final shape. The other is to take large deformations in each step, but soften the metal by annealing or normalizing, at frequent intervals in its progress toward final shape. Practically, a combination of both methods is used. While it costs money to make the extra dies for intervening steps, and to restamp the part several times, yet the rate of production is so rapid that it is usually cheaper to use several steps of mild deformation than it is to anneal once. Hence, the tendency is to wring out of the metal every last bit of deformation it will stand before resorting to an anneal.

Hence, the maker of deep stampings wants material that will stand very severe treatment between anneals. The more it will stand, the lower his cost of production. He will always gear up his drawing process to utilize the most deformable metal he can obtain in uniform quality. If the quality falls below the slight margin of safety that is allowed, he meets undue breakage, and his costs go up. So he demands high and uniform quality.

In this connection, quality means adaptability to the forming process. The finished product is seldom highly stressed and the final properties may ordinarily vary considerably without affecting the utility of the part produced. This is not always true, and properties of the finished article are sometimes sacrificed in order to get low forming cost, but in the vast majority of cases, the forming qualities are the important ones. The evaluation of quality of metal is therefore of little concern to the user of the product, but it does vitally concern the maker of it, and in turn, the producer of the sheet.

The requirements will steadily become more severe. Younger[1] comments on the trend toward large integral pressings in the automotive industry, requiring die design of a very superior order. He says that, for low priced cars, it may be feasible to press the whole half of the



By comparison with the men, the size of this drawing press at the plant of the Youngstown Pressed Steel Co. can be estimated.

* Director, Battelle Memorial Institute.
† Chief Engineer, Budd Wheel Co.

THIS report will be welcomed by all those who are interested in the process of pressing metals in various forms. It will also render a timely service in stimulating discussion. The problem of determining the deep-drawing qualities of metals has a certain similarity with others in the metal-producing industry. It was frequently thought in earlier times that certain mechanical qualities of our metals of construction may be determined by simple mechanical tests such as the tensile, the bending, the impact or the hardness test. As more knowledge became available, it was recognized that it was necessary to distinguish more accurately among the mechanical properties of metals and it became necessary to investigate these properties by means of a number of more or less independent methods. Something similar will probably occur also when the deep-drawing qualities of metals

QUALITIES of Sheet Metal

Discussion by C. L. EKSERGIAN†

body including the dash, and butt weld it to the other half. That is the sort of deep-drawing job for which material must be provided in the future.

In such a situation, disputes between steel maker and steel user necessarily arise, the one claiming that the steel was all right, but that the user's practice is in error; the other that his methods are correct, but that the steel is not up to standard. To settle such disputes, an acceptable standard of deep-drawing properties and acceptable methods of testing for conformity to the standard are sorely needed, but are not available.

People experienced in deep drawing of steel tell us that 20 lots of sheet can be evaluated by all the physical, chemical, metallographic and other tests now commercially applied, and appraised as identical in every way, yet, on the average, one lot of the 20 will show quite high breakage, with the press practice remaining as it was on the 19 others, of which every sheet may have gone through perfectly. The line of demarcation between the material that works only fairly well, and that which behaves perfectly is so fine, these users say, that it is not brought out by present tests, and there is no way of specifying the better product. The user believes that the trouble lies in the steel, but he cannot define the trouble in terms of measurable physical properties that might help the steel maker locate the difficulty.

Steel mills tell us that the maker of deep stampings may find that consecutive shipments from the same steel mill do not act alike. The stamper, though, is sure no changes have been made in his practice, so he rejects the shipment that does not work well on his presses. The steel maker takes it back, and there have been cases where, having had another rejection from another customer with a similar complaint, he then sent to each the material rejected by the other, with the result that both found the replacements satisfactory. The steel maker is satisfied in such cases that the variable is wholly in the user's practice.

It is perfectly obvious that either or both the pressing practice and the material itself may be at fault in the case of failure to produce the desired result. Among the variables that may enter into the process, as distinct from the material, are:

Design of punch and die, including radius of curvature over which the metal must flow.

Clearance between punch and die, in relation to thickness of metal, amount of deformation and type of deformation required in each step.

Amount of force applied and rate of its application, hold-down pressure.

Friction between punch and die and sheet, as affected by nature of punch and die surface and by lubrication.

Among those variables that enter from the material itself are:

Thickness of sheet.

Uniformity of thickness and uniformity of properties in different directions.

Resistance of the sheet to initial deformation (yield point).

Resistance of the sheet to breakage (ultimate strength).

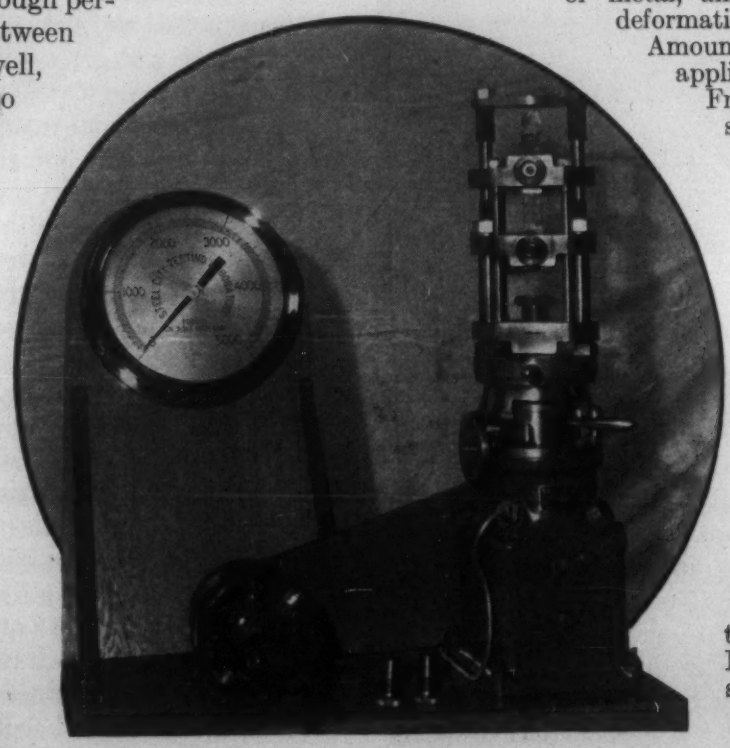
Ductility of the sheet, both for general and local deformation.

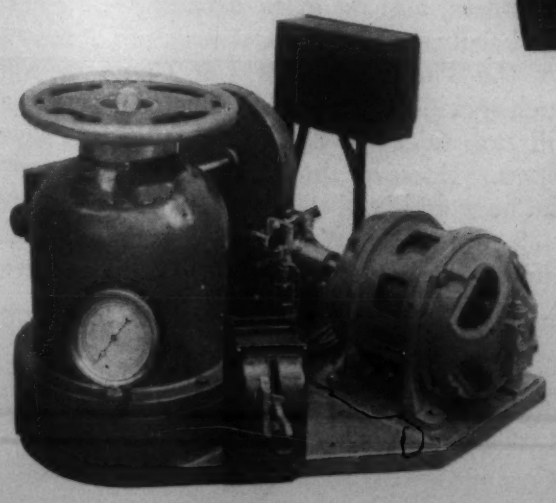
Nature of surface, as regards friction.

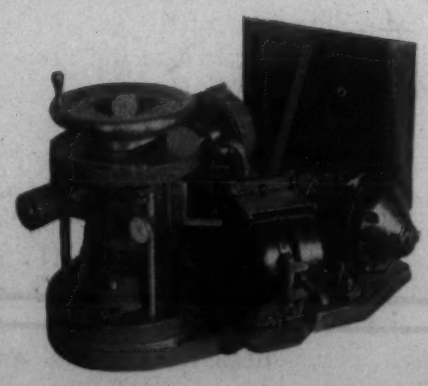
Nature of surface as regards ability to draw smooth.

Rate of work-hardening, stiffness and spring-back.

Obviously both the die design and the amount of deformation the sheet will stand are dependent upon the thickness of the sheet. Increasing the thickness of the sheet by a trace without changing the properties of the metal at all may avoid difficulties, and many sheet makers tend to make the gage of their deep-drawing sheets a trifle full.



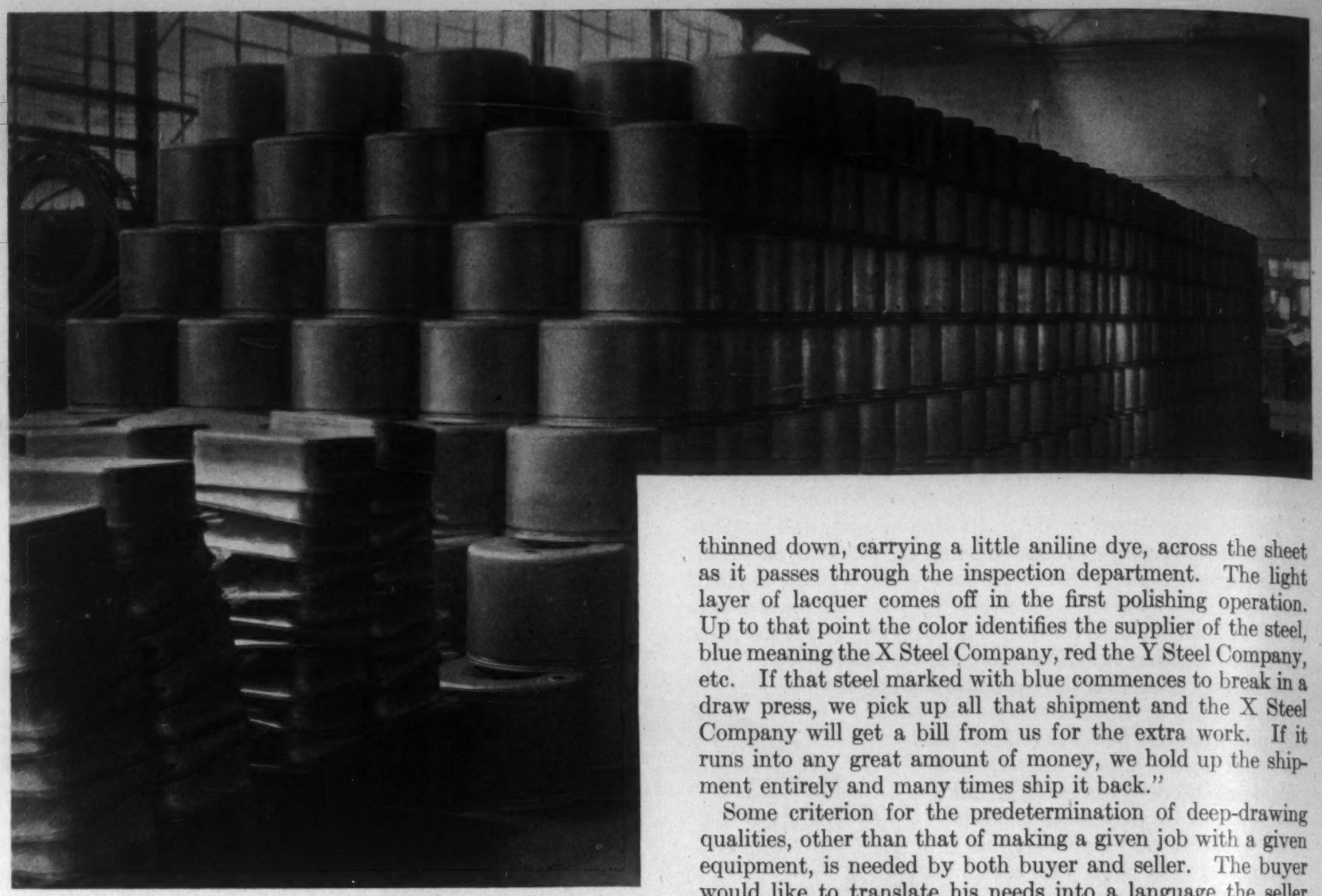




Above, Combined Ductility (Siebel and Pomp) Testing Machine (Steel City Testing Lab.). Left, 60,000-lb. Capacity Motor-driven Testing Machine for Plates; and, right, a Smaller Capacity Motor-driven Ductility Testing Machine for Sheets. (Tinius Olsen Testing Machine Co.)

will be further investigated. It would seem that these qualities depend on a number of important properties of all our engineering materials. In these questions, plastic flow under combined stress (the action of combined forces in various planes) is involved as well as the question of rupture (also under combined stress). Furthermore a number of other factors may have a great influence. Among these may be, for example, residual stresses produced by previous plastic deformation, structural changes in the material, heat treatment and many other points. The natural trend of the development will lead to the investigation of all these factors in greater detail. As more information about these factors will become available, the need for a general testing method may become less important. A. Nadai**

** Mechanics Division, Research Laboratories, Westinghouse Electric & Manufacturing Company.



Fortunately, the accurate measurement of thickness and checking it by weighing a given area of sheet, are easy. Nevertheless many of the misunderstandings are due to differences in sheet-thickness rather than to other factors.

But granting that sheet of definite thickness is to be employed, we still have to differentiate between variations in drawing practice and variations in material. It might perhaps seem that the user could mark off his sheet into the "checker-board," form it and measure the part being made, in its various stages and, then order from the steel mill sheet of a given thickness with a certain percentage elongation in a certain length with certainty that if the sheet met that specification, it would work well in the press. But the matter is not so simple. Other factors enter in and what he usually does is to send the steel maker a blue-print of the part to be made, perhaps with some information as to the die design and number of steps between anneals, and ask the steel maker to supply material that will satisfactorily form the part.[2] The steel maker has to take the order on that basis, and hope for the best. He cannot duplicate the press and dies on which the material is to be used, so the service test has to be made by the customer. If the steel maker has found that a certain schedule of pass reduction and annealing or normalizing has produced a sheet that worked all right in making a similar product at another customer's plant, he ships material as near like the former sheet as possible. But if practice at the two plants is not identical, the new shipment may not be suitable for the second plant. The failure of the sheet to handle the job is equally irritating to the buyer and seller of sheet. So both would like to make sure that the sheet will do the job before it leaves the sheet mill.

Van Derau[3] has described the procedure about as follows: "We found one of our greatest difficulties was to know whose steel was giving trouble. We may have steel in process from several makers, and as soon as it is sheared or blanked the identification is lost. So we draw a strip of lacquer, much thinned down, carrying a little aniline dye, across the sheet as it passes through the inspection department. The light layer of lacquer comes off in the first polishing operation. Up to that point the color identifies the supplier of the steel, blue meaning the X Steel Company, red the Y Steel Company, etc. If that steel marked with blue commences to break in a draw press, we pick up all that shipment and the X Steel Company will get a bill from us for the extra work. If it runs into any great amount of money, we hold up the shipment entirely and many times ship it back."

Some criterion for the predetermination of deep-drawing qualities, other than that of making a given job with a given equipment, is needed by both buyer and seller. The buyer would like to translate his needs into a language the seller can understand. Such a language would be in terms of specification of properties to be determined by some quantitative method of testing. Of course, there have been attempts to set up this language. In the case of very thick sheet or thin plate, Morton[4] finds that the usual language of metal specifications, the tensile test, is adequate. For the deep-drawing of certain articles from 0.25″–0.30″ plate, he finds that suitable properties, (given a minimum of inclusions) are such combinations as 50,000 lbs./in.^{2} tensile with 40% elongation or 64,000 lbs./in.^{2} tensile with 33% elongation.

In thinner sheet, 18 or 19 gage, Graves[5] specifies, for S.A.E. 1010 steel, on deep-drawing stock 10.5 mm. Ericksen, 43 to 53 Rockwell B hardness, and on extra deep-drawing stock, 11 mm., the same hardness, and grain size as per standard sample. He says the Packard Motor Car Company will accept sheet on such specifications, and if the stocks meet the specifications, will not reject it should it cause excessive breakage in the press. However, in discussion of this paper, W. F. Graham said he would hold the hardness to 50 B maximum instead of 53, and J. M. Watson said it would be a dangerous procedure to take these standards into another plant, and expect them to work out satisfactorily.

Watson[6] later again stated that a correlation between laboratory ductility tests and plant usage might be worked out in one plant, but the same correlation would not hold for another plant.

Brown[7] shows plots indicating that an Olsen depth of 0.45″ and Brinell hardness of 67–80 in 16 gage blue annealed or box annealed sheet, are required to avoid excessive breakage in the press.

Winlock and Kelley[8] state that no test is adequate unless correlated with the shape of the stamping, that the tensile strength and yield point are not good criteria, either one showing only a 50% correlation, and that the ratio of the two is not very helpful. Elongation figures (both longitudinal and transverse) are helpful. In one comparison, it was found that 37% longitudinal, 34% transverse, elongation in 2″, or 25% in 8″ was necessary. 83% of the specimens passing

either limit worked well in the press. They did not find the bend test very useful.

However, it seems generally considered that, were it feasible to get accurate figures for reduction of area in tensile testing of thin sheet, such figures would be useful, and Sachs and Sieglerschmidt[9] find that repeated bending, under controlled conditions, over a sharp radius gives values corresponding to reduction of area.

Godsell[10] finds the repeated bending test useful in showing variations in directional properties, and Skerry[11] finds uses for the bend test.

Making accurate tensile tests on thin sheet, especially when elongations are determined on more than one gage length, and when both longitudinal and transverse tests are made, is rather time consuming.

Hence, the ball cupping test, such as is made on the Erichsen,[12] Olsen,[13] Guillery and Wazau[14] tester is generally used for ductility measurement, often with measurement of the load required. The Wazau apparatus* allows control and measurement of hold-down pressure as well as measurement of die pressure at each stage of the cupping process. The ultimate tensile strength is often omitted and that factor brought into consideration by means of a hardness test, usually the Rockwell because of its greater reliability on thin sheet. The cupping test has obvious advantages in that it tests the sheet in all directions, it gives a deformation somewhat analogous to that of deep stamping, and does it without introducing press variables such as die clearance. Both this and the Rockwell test are quickly and cheaply made.

The ordinary cupping test is not a very precise one, nor does it reveal fine distinctions among different steels. Marked differences in drawability as met in service are revealed only by a few tenths of a millimeter differences in the Erichsen values. A given Erichsen value on brass, aluminum and deep-drawing steel does not mean that those alloys will all act the same under the press. Kummer[15] finds at least a third of the Erichsen indications are out of line with press results. Schmidt[16] quotes Kummer, but he also quotes Aumann's[17] opinion that the Erichsen test does show fair correlation. On his own authority, he states that the tensile strength does not show drawability, which depends on "cold-workability."

It is stated[18] that a questionnaire showed 75% of users of the Erichsen test to be dissatisfied with it, and to feel that it gives erroneous conclusions, only 15% believing that it gave some idea of drawability.

Daeves[19] finds the data usually used to show the changes in Erichsen values that are to be expected with different thicknesses of sheet of the same quality, to be inaccurate and proposes a different relationship.

Eksergian[20] and, in discussion, Nagel, are not enthusiastic about cupping tests telling the whole story.

Green[21] thinks the Erichsen test is useful, but weak in that thicknesses of sheet are not adequately compared.

Anderson[22] considers the test as reliable and simple but not as reliable as the dynamic ductility test.

Other observers[23] prefer a deep drawing test in which a conical cup with an angle of 30° to 35° is made, and show photographs of cones from materials of Erichsen values ranging only from 8.5 to 8.7 which show much greater differences on the cone test, some rupturing, others showing a very coarse surface and others a smooth surface.

In the Allgemeine Elektricität Gesellschaft[24] deep-drawing test which is claimed to be an improvement over the Erichsen test, a 50 mm. punch is used to force a disk of the sheet to be tested into a cup. The die clearance, by the use of various die rings, is adjusted to 50 mm. plus twice the actual thickness of the sheet plus a small tolerance. A series of centering and spacing rings of thickness corresponding to the sheet to be tested, and of inside diameter to take test disks of a specified size, are provided. The proper one is chosen and the test disk, made of a pre-determined diameter, is set into it, and the cup pressed out.

The diameter of the test disk for steel sheet of 0.1 to 2.5 mm. thickness is given as 100 mm. for steel for simple work, 102 mm. for that for average work and 103.5 mm. for that for difficult work. These diameters have been set up as a sort of "must go" test in which the specimen must be drawn down into a 50 mm. I.D. cup (which would be 40 mm. high inside for an 0.3 mm. sheet and 37 mm. for one of 2.5 mm. if the diameter of the test specimen were just 100 mm.) over a punch with 7 mm. radius between the flat face and the cylinder, and show

* See Abstract page 204.

On facing page, finished stampings; and on this page, a typical press, both at Youngstown Pressed Steel Co.

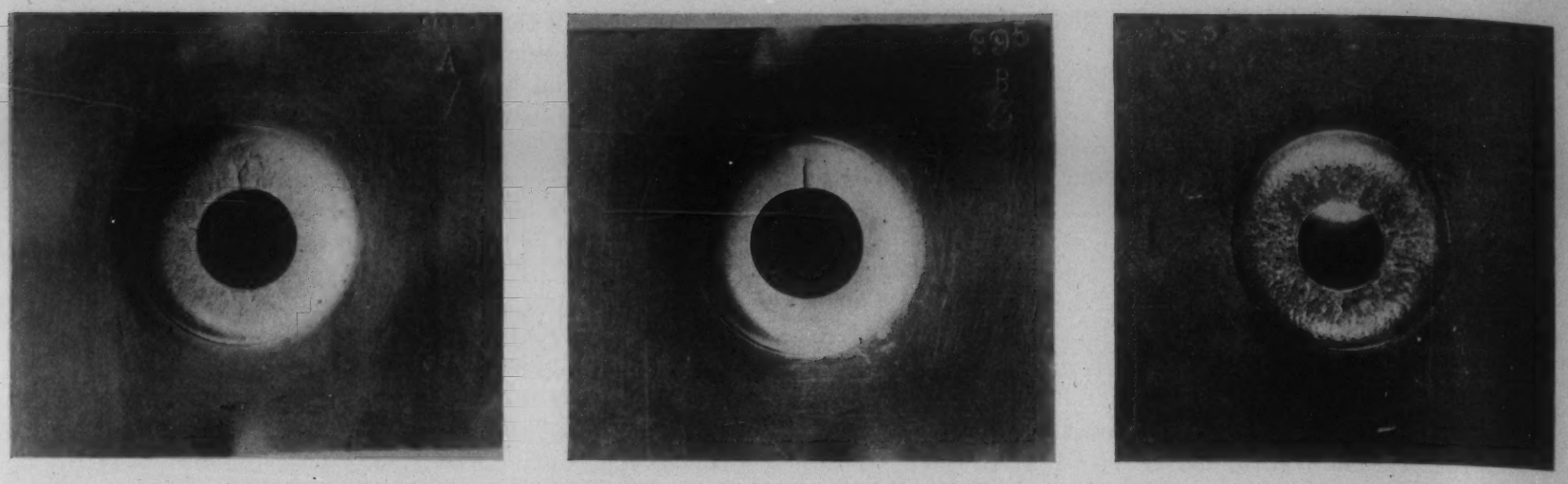


Fig. 1. Hole-widening Test Specimens—after Siebel and Pomp. (1a) is an aluminum sheet with coarse crystalline structure; (1b) is one with fine structure. Note the much larger distention of the hole in (1b) before failure. (1c) shows a hole-widening specimen of coarsely-crystalline steel sheet.

both absence of cracks and a smooth surface. If the material would stand a more severe draw (form a larger diameter disk into the standard diameter cup) this is not determined in the usual way of using the test.

It is claimed that the results, unlike those of the Erichsen test, agree with practice.

The American Society for Testing Materials[25] is advocating the tension test for acceptance or rejection on rolled tempers of sheet high brass, with a grain size requirement on annealed material. The cupping test is not imposed.

Adelson[26] points out that different mills put out steel sheet of hardness in different tempers, and gives an interesting table of Olsen, and Erichsen cupping tests, bend tests and Rockwell, Scleroscope, Brinell, Vicker and Herbert hardness tests on sheets that have different pass reduction, but unfortunately this was not extended to show the performance in actual stamping and drawing practice.

Lawrence[27] points out that cupping tests plus Rockwell hardness plus microscopic examination are all necessary, the latter since the physical records may be practically identical, and yet heavy breakage be encountered in the press due to wrong microstructure or presence of inclusions. Tensile tests are helpful, but all the tests must be correlated with the action of the sheet in the press.

The more or less standard tests applied to show the drawability of metal are evidently not sufficient to tell the story, unless they are interpreted in the light of sound experience. Satisfactory specifications for purchase and sale would be hard to draw at present. This appears to be due either to failure to measure exactly the properties involved or to lack of understanding of the variables that exist outside the metal. There has been a good deal of recent effort, especially in Germany, on the study of the deep-drawing process, with its variables as the object of study rather than the properties of the metal. This work has mostly been done on the drawing of a simple cylindrical cup from a disk. Books or articles on various phases of this study have been published by Ackermann, Brasch, Draeger, Fischer, Jones, Kaczmarek, Kühner, Kurrein, Musiol, Ruhrmann, Sachs, Sellin, Sommer and others.[28]

While these investigations were often made on various materials on which tensile and Erichsen figures were usually available, no very definite conclusions can be drawn as to the relation to the ordinary physical tests with drawability. The work was usually done with an eye to information along lines of mechanical engineering, rather than those of metallurgy or mechanical testing.

We may next consider some of the more uncommon methods of testing. Straw[29] and co-workers use a method somewhat similar in principle to the cupping test. V-shaped punches are ground, one to a sharp 90° tip, the tips of the others being accurately rounded to $^1/_{64}$, $^1/_{32}$, $^1/_{16}$, $^3/_{32}$ and $^1/_8$ inches. These work into a die with a sharp 90° notch, the distance between punch and die at the end of the down stroke being equal to the thickness of the sheet to be tested. The results ranged from smooth bends, through sound bends with an orange peel surface, to those that crack. The method has been used to determine the radius required for an acceptable bend of a given non-ferrous sheet.

Jovignot[30] points out that the Erichsen test has difficulties in that the appearance of the first crack is not necessarily detected. Hence he fixes a Guillery type apparatus to use hydraulic pressure instead of a ball. The oozing out of a drop of liquid shows failure.

The results do not agree at all with the Guillery ball test. A table of depth in mm. and coefficient of deformation compared with the ball test gives, for depths of 9.1 to 9.6 mm. on the ball test, the following on soft steel:

Hydraulic Test		Ball
Depth, mm.	Coefficient	Depth, mm.
8.0	7.1	9.5
10.8	13.0	9.3
12.5	17.3	9.3
13.0	18.7	9.2
13.7	20.8	9.6
18.5	38.0	9.4
19.4	41.8	9.5
19.5	42.2	9.1
20.0	44.4	9.1
20.8	48.1	9.2
21.0	49.0	9.4

No proof is given that the new method bears any relation to the drawability of the metal.

Some years ago the Bureau of Standards approached the problem by means of a spinning test, in which a specimen was spun back over a mandrel in the shape of a frustum of a cone, rotating the mandrel on a lathe at a fixed speed and spinning the sheet with a tool having a ball-bearing in its nose, which was pressed against the work under a definite load. If the taper was too great the sheet would break. The greatest angle of taper over which the sheet would spin without breaking was a measure of the ability of the sheet to be deep drawn. While this appears to involve pure deformation only, and hence to be a suitable test, it requires several specimens, to be spun over mandrels of varying tapers.

Siebel and Pomp[31] have suggested the "deep-drawing-widening" test in which a round hole is cut in the sheet and a flat punch forces the sheet into a cup, with the hole in the bottom. The hole is stretched in all directions. See Fig. 1. The diameter to which the hole may be extended without cracking shows the ability of the sheet to stand deformation. Obviously the condition of the edge of the hole is highly important in such a test, and the smoothing and polishing that may be necessary to make the test reliable would be a drawback.

Two sizes of holes were tried. On some materials and thicknesses of sheet the percentage widening agreed well, but on

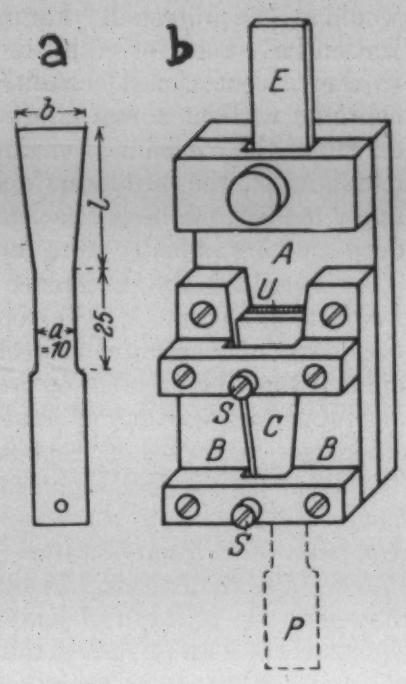


Fig. 2. The Wedge-Draw Test, after Sachs. (2a) shows the standard specimen, width 10 mm. (0.4″) straight section 25 mm. (1.0″) long, dimensions l and b varied to suit the material. The taper is 1 in 5. (2b) shows the wedge-shaped die. On the base A is fastened the die B. The face-plate C is adjusted by the screws S, and a spacer U, to the thickness of the sheet. The whole die is gripped in the upper jaw of the testing machine through E, and the specimen P, is gripped in the lower jaw. The specimen either pulls through the die, pulling down to the width a in (2a) or else pulls part way through and breaks at a.

others there was some variation. Using a given hole, check results usually did not agree quite as closely as the Erichsen values did, but the figures for different materials were more widely separated than the Erichsen values.

Selected Values from Data of Siebel and Pomp

Material	Thickness mm.	Widening % 12 mm. hole	Erichsen	Thickness mm.	Widening % 12 mm. hole	Erichsen	Thickness mm.	Widening % 12 mm. hole	Erichsen
Pot annealed steel sheet	0.31	49	10.1	0.52	58	10.1	1.05	70	11.1
Continuous annealed steel sheet	0.30	40	9.5	0.51	64	10.5	0.98	83	11.5
Deep drawing sheet	0.29	65	9.8	0.50	85	10.8	1.05	110	12.1
18-8 sheet	...	...	...	...	...	...	1.00	129	16.6
Al	0.28	36	10.9	0.57	55	11.6	0.98	75	12.7
Cu	0.29	44	12.5	0.58	67	13.7	0.98	86	14.0
Brass	0.31	61	15.0	0.58	92	14.9	0.98	115	15.5

Tallow was used as lubricant in both widening and Erichsen tests.

Plotting Erichsen against percent widening for all the materials gives a shot-gun curve, but the data for the three carbon steel sheets shows a much higher widening figure on the special deep drawing sheet than would be indicated for the Erichsen-widening percentage ratio on the basis of the other sheets.

Cournot[32] speaks approvingly of this test, and considers it more discriminatory than the usual cupping test.

Sachs[33] has proposed a "wedge-draw-test" in which the test is aimed to show the performance of one sector of a disk as it is drawn down into a cylinder. To simulate this, the specimen is like a tensile specimen, but one on which the 10 mm. wide breaking section is straight for 25 mm. but then tapers out to a wider width—by a taper of 1 in 5. The length of the tapered portion and hence the width at the top of the specimen is chosen according to the material to be tested.

A wedge shaped die is provided whose throat is 10 mm. wide, and whose taper is also 1 in 5. See Fig. 2. The thickness of the die opening is adjusted by a flat plate held in by adjustable screws so that it is just equal to the thickness of the test specimen which lies flat in the die. The die is mounted in the upper grip of a tensile testing machine and the lower part of the specimen is held in the lower grip. The specimen is then pulled through the die, the specimen having to deform so that the broad top of the wedge pulls down through the 10 mm. throat of the die. If the specimen is not too long, it will pull through the die without breaking. If it is too long, the straight lower portion of the specimen will neck down and finally break, leaving the upper portion in the die. The ratio of the width of the top of the wedge shaped portion of the specimen to the length of that portion, on the longest specimen that just pulls through (i. e., when the stress to pull through equals the stress to break the straight portion or when half of a set of specimens pull through and half break) is the "deformation number."

The power required to pull through specimens of lower ratio, when plotted against the ratio, gives a fairly straight line. When the proper ratio at which a good sample of a given material in a given thickness should draw through without breaking has been determined by testing a number of specimens with varying ratios, that length of wedge can be used for the routine examination of other samples of similar materials, which should also draw through if they have the same "drawability."

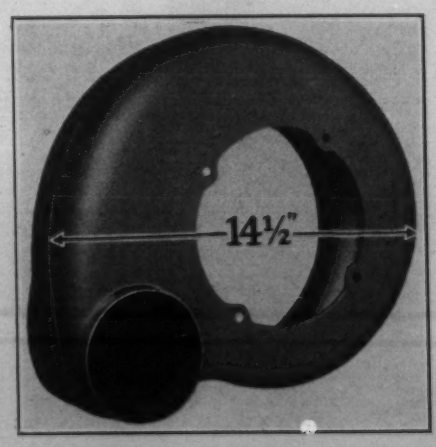
Data to show the ability of the test to pick out material that will not draw well, or by which it may be compared with the ordinary cupping test, are lacking.

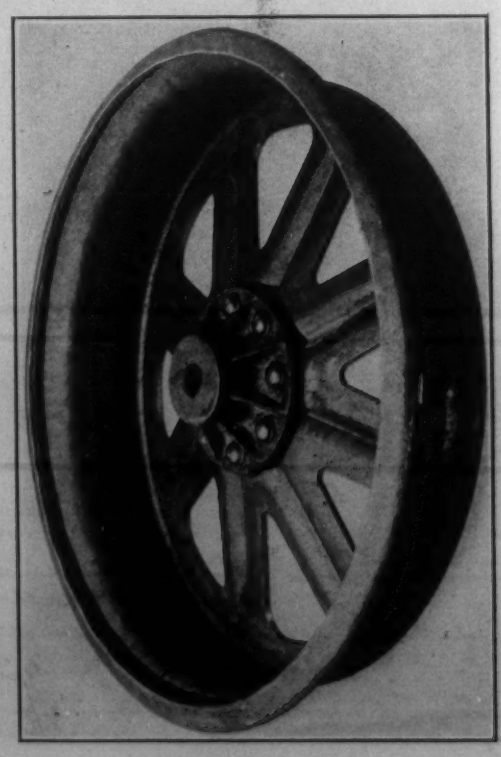
The same apparatus is adjustable to different thicknesses of sheet. The effect of different lubricants is clearly shown, aluminum of 12,500 lbs./in.^{2} tensile in 0.06″ thickness has a drawability number of 1.85 when tallow is used, and only 1.61 when drawn with rape-seed oil as lubricant.

In relation to lubrication, Miller[34] states that some draws that cannot be performed with a tallow lubricant, can be, with one of tallow and flour.

A property that is seldom measured directly is the rate of work-hardening upon deformation. (See comment under repeated bending.) This should be of interest in regard to austenitic sheet of the 18 Cr 8 Ni type. According to Houdremont[35] the Erichsen values for 18-8 sheet only run from 14.4 to 15.5 as the thickness of sheet increases from 0.02″ to 0.08″ while those for deep drawing carbon steel in the same range of thickness rise from 8.3 to 12.1.

Crane[36] has attempted, by using recording testing machines in the tests of standard specimens, to get a picture of the progress of strain hardening. Work is being done in this country, but is as yet unpublished, in getting very exact records of stress-strain diagrams in tensile testing of thin sheet under conditions where lag of the weighing mechanism is eliminated. Other unpublished work is being done in the impact-tensile test, in the hope that by testing at a rate comparable to the rapid rate at which deformation takes place in commercial





Pressed steel fan housing, weight 8.5 lbs., replacing a casting which weighed 24.5 lbs. At right, pressed steel wheel, weight with hub 47 lbs., diameter 20″ on tread. Casting replaced weighed 125 lbs. (Courtesy of Youngstown Pressed Steel Co.)

die pressing, since tensile impact[37] may result in four times the elongation shown by the same material when tested at a normal rate, useful data will result.

It is well known in the case of zinc that the rate of deformation has a major effect and most testing of the drawability of zinc sheet and strip is done on the Olsen dynamic ductility tester or some similar apparatus.[38]

The study of directional properties in sheets, which causes "earing" has been studied[39] by means of X-rays and clearly connected with the grain orientation thus revealed. Theoretical study of this orientation has been carried quite far, especially by Wever[40] and by Sachs[41] and co-workers.

In all of the work that has been done, there seems to have been no concerted effort to select a number of lots of material which have given good and bad results in deep-drawing of similar objects in practice and compare the various methods of test in one laboratory, with check determinations in other laboratories to see which ones best suit the materials in accordance with service results and which methods give the most reliable and reproducible data. Nor does there seem to have been any effort to select material which is on the dividing line as to "drawability" for the production of a given object, distribute this to a number of plants and compare their service results with differences in drawing practice, die design, forming speed, lubrication and the other variables that are concerned.

Until such coöperative investigations are made, it seems to be far too pessimistic an attitude to assume that it is impossible to so evaluate deep-drawing methods and materials that acceptable standards may be set and acceptable tests developed by means of which one might prove that a given sheet was or was not of proper deep-drawing quality. If sufficiently reliable tests were available, and such tests showed a given material to be of proper quality for the forming of a given part, the failure of any plant to get satisfactory results with that material would then be taken as proof that the plant practice needed overhauling rather than that the material should be rejected. Thus, the producer would be protected.

Conversely, such a test would pick out sheet that truly was not up to standard, and would prevent it from being sent out on a job it could not meet. Hence, the consumer would also be protected. Far more difficult cases of standardization have been solved in the past. The economic loss due to the present chaotic condition should not be allowed to continue without a real effort to see whether the combined efforts of the mechanical engineer, the testing engineer, the metallurgist, the producers and the users of sheets cannot apply modern methods of scientific research to extricate the deep-drawing industry from its present dilemma.

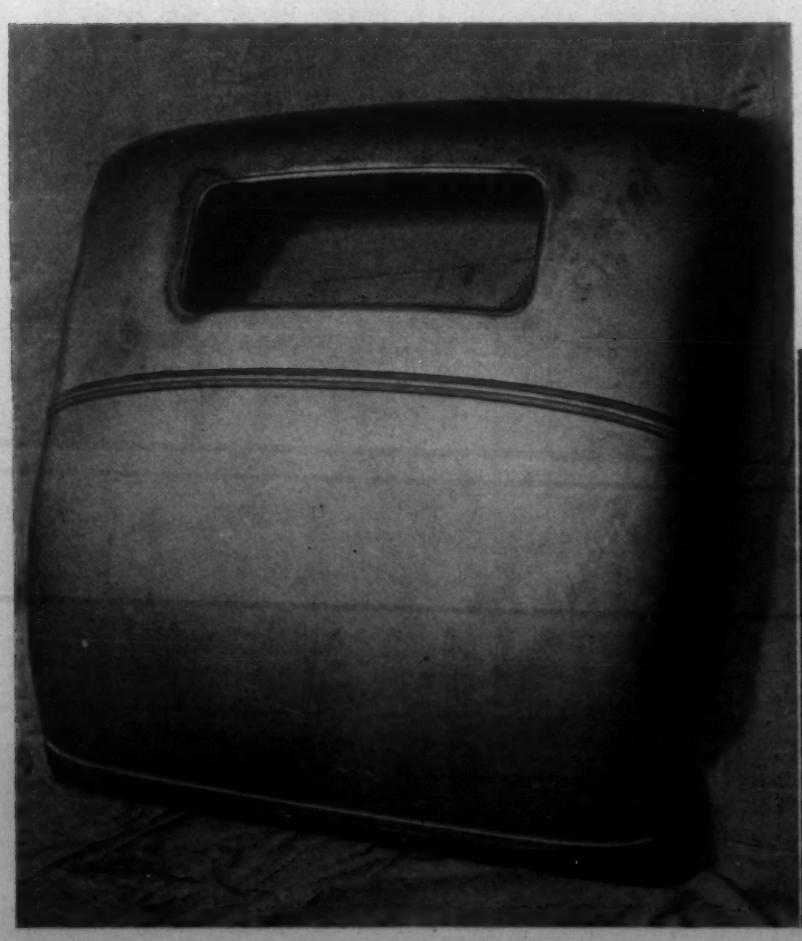
At a preliminary conference called by the Pressed Metal Institute in December 1930, representatives of producers and consumers of deep-drawing steel showed distinct unanimity of opinion that the problem of pre-determination of deep-drawing properties was one of joint interest and importance. A committee comprising representatives of the American Society of Mechanical Engineers, the Society of Automotive Engineers, the American Society for Testing Materials, the American Steel Manufacturers Technical Committee and the Pressed Metal Institute has been appointed to give consideration to the problem of joint action. Both producers and consumers will await such action with a great deal of interest, and not without hope that the situation may ultimately be vastly improved if all can get together for a real study of the problem.

Discussion: by C. L. Eksergian*

The chaotic condition which this cross-sectional digest reveals is none other than that which is to be expected when we appreciate the method of attack which has been applied to sheet metal testing. In general, the attitude has been to apply a given test or tests to the material without particular reference to the nature of the draw. In short, attention has been confined mostly to the material rather than to an analysis of how that material is asked to behave while undergoing deformation. We therefore find ourselves equipped with various methods of determining, respectively, the various characteristics of the material. In some cases the characteristics revealed by a given test are critical for the draws in question and accordingly a conclusion is drawn that such a test is the final answer. However, when another investigator applies this test to his system of draws in which other characteristics are critical this test fails. Hence, the disagreement between investigators and the general chaos in the whole field of testing.

To sum up the situation briefly we should not attempt to determine, say, the electrical conductivity of the material,

* Chief Engineer. Budd Wheel Co.



Pressed steel automobile body parts: At left, back panel. Below, whole side, made from sheet measuring 64″ × 108″ and 0.043″ thick (No. 19 gage). The stamping is all one piece except for the "drip molding," spot welded in place after

by its Brinell hardness (unless we know a definite correlation exists between the two). Similarly, we should not apply the yardstick of ductility as revealed by the various tests when the major characteristic required may be strength. Or again we should not apply the yardstick of ductility as revealed by the Olsen cup test even though the criteria of the draw is stretch, unless this stretch is highly localized. If the stretch is over an effectively long gage length then only the ductility of general extension should be applied as a yardstick.

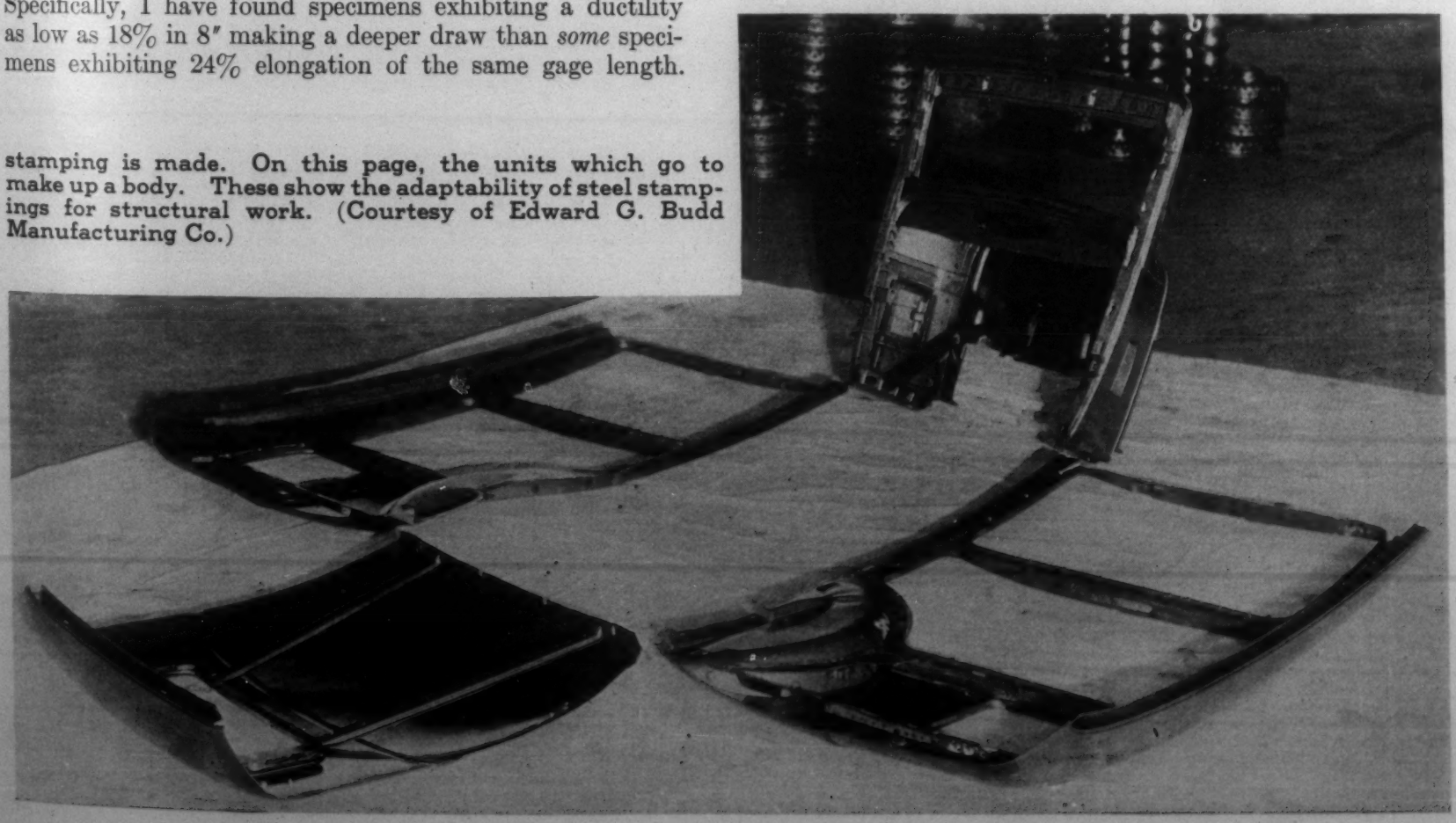
Again there are many instances where two or more properties of material are simultaneously critical. In the case of the two properties both may not necessarily have the same weight, one being more influential than the other for the particular type of draw in question. However, they both must be regarded simultaneously in light of their respective weights (i. e., merely because one has greater weight than the other does not justify ignoring the minor one). Lack of the above consideration constitutes one of the most flagrant causes for disagreement between tests and performance. For example, the need for considering yield point and tensile strength along with ductility is sound from the angle of reason, when one considers that in practically every draw the resistance of the material under compression (yield point) as well as the strength (tensile strength) of the material in pulling its latter regions through the desired deformation, enters into the overall behavior requirements. It is the inability to interpret yield point and tensile strength with ductility for a given type of draw that causes one to feel pessimistic toward the possible value of a knowledge of yield point and tensile strength.

However, it should be remembered if the type of draw is largely a question of stretch then the weight of these physical properties is of minor consideration. In such draws as the forming of cylinders in which the material undergoes a rearrangement rather than a stretch (i. e., that the surface area is not necessarily increased at the expense of a reduction in thickness) the physical properties of yield point and tensile strength have considerable influence.

As a matter of fact in some investigations which I have carried on, but have not yet published, covering the forming of a simple cup the necessity of considering yield point and tensile strength with even greater weight than ductility is striking. It should not be construed, however, that the consideration of ductility can be omitted as explained above. Specifically, I have found specimens exhibiting a ductility as low as 18% in 8″ making a deeper draw than *some* specimens exhibiting 24% elongation of the same gage length. This was due to the fact that the 18% specimen had other advantageous physical properties which more than compensated for the increase in ductility present in the 24% specimens of lower physical properties. Note that I particularly mention "some" 24% specimens. Other 24% specimens which showed as high or higher physical properties than the above mentioned 18% specimen showed even a superior performance.

Attention should be assigned, first to an analysis of the type of deformation to which various sections of the material is subjected in the draw. After this sytem of plastic straining has been clearly established in detail then it is necessary to devise tests which similarly deform material. With this combination of data at hand the material in question can be subjected to the necessary tests which are *critical for the type of draw in question* and accordingly, a predetermination of fair reliability should be able to be made as to the ability of material to successfully form. Tests which accurately deform the material under the same system of straining to which it is imposed in the draw are not easily found. In fact, the majority of conventional tests are lacking in many of the cardinal requirements. Take for example the simple tension test. Here the specimen is pulled in one direction with complete freedom of deformation in the other two, namely, width and thickness. Practically never does such a condition arise in a stamping. Even though we confine ourselves exclusively to pure stretch in the stamping, under pure stretch the deformation of the width is either restricted or definitely pre-defined so that the *critical* elongation realized in the simple tension test is not present.

It may be argued that in the Olsen cup test such is not the case, for here stretch is obtained at the complete expense of reduction in thickness, there being an increase in the effective width or area. However, the shortcomings of the ductility test lie in the fact that the type of stretch simulates that of local extension. We know that there does not exist a constant relationship between local extension and general extension for various materials. Specifically, given two materials A and B, the local extension of A may be considerably greater than that of B, even though the general extension of A is considerably less than that of B. Henceforth, if the criterion of the draw is that of general extension, obviously



stamping is made. On this page, the units which go to make up a body. These show the adaptability of steel stampings for structural work. (Courtesy of Edward G. Budd Manufacturing Co.)

the results of the Olsen test are not necessarily indicative.

It was interesting to learn of Sachs' principle of a "Wedge-draw-test." Not that I wish to unduly dwell on the subject of priority I would like to point out that in 1925-6 the writer developed a test identical to this but never published it. There is considerable merit in this type of test but we met many obstacles largely due to friction, which severely upset our results and effort in this direction was temporarily dropped. I am now working on a modification of this test which it is hoped will surmount the obstacles present.

This complete digest of the present field of sheet metal testing should go a long way toward stimulating successful activity. The wide diversions of present opinion are based upon too slight evidence. With sufficient facts, opinions will adjust themselves to the facts. What we need now is more evidence.

REFERENCES

[1] J. Younger. Editorial, Making Big Ones Bigger. *Automotive Abstracts*, Vol. 9, May 1931, page 130.

[2] J. L. McCloud. Steels Used in Ford Industries. *Metal Progress*, Vol. 19, March, 1931, pages 33–39. E. E. Thum. Editorial, same issue, pages 68–69.

[3] C. Van Derau. Discussion of Electroplating on Cold Rolled Steel by G. B. Hogaboom. *Monthly Review, American Electro-Platers Society*, Aug. 1931, page 16. Quotation condensed.

[4] H. T. Morton. How to Select Thin Plate for Deep-Drawing. *Metal Progress*, Vol. 18, 1930, pages 54–59.

[5] W. H. Graves. Sheet Steels for Automobiles. *American Society for Testing Materials*. Symposium on Developments in Automotive Materials, March 19, 1930, pages 18–27. Also *Metal Stampings*, Vol. 3, May, 1930, pages 443–444.

[6] J. M. Watson. Steels for American Automobiles. *Metal Progress*, Vol. 19, 1931, pages 33–37.

[7] L. N. Brown. Selecting Material for Formed and Drawn Parts. *Transactions American Institute Mining Engineers*, Vol. 69, 1923, pages 932–942.

[8] J. Winlock & L. Kelley. Testing Automobile Body Sheet Steel. *Transactions American Society for Steel Treating*, Vol. 12, 1927, pages 635–650.

[9] G. Sachs & Sieglerschmidt. Prüfung von Seildrähten durch Zug-und Biegeversuche. *Mitteilungen der deutschen Materialprüfungsanstalten*. Sonderheft X, 1930, page 68.

[10] J. C. Godsell. Repeated Bending Test for Soft Steels. *Swansea Technical College Metallurgical Society*, 1930, abstracted in *Stahl und Eisen*, Vol. 51, March 5, 1931, page 302.

[11] E. Skerry. Methods Employed in the Mechanical Testing of Aero Strip Steel. *Aeroplane*, London, Vol. 38, Feb. 28, 1930, pages 352–353.

[12] A. M. Erichsen. Ein neues Prüfverfahren für Feinbleche. *Stahl und Eisen*, Vol. 34, 1914, pages 879–882.

[13] L. N. Brown. Practical Testing of Sheet and Strip for Drawing Operation. *Metal Stampings*, Vol. 3, March 1930, pages 239–242, 270.

[14] P. W. Döhmer. Der Tiefziehprüfer Bauart Wazau. *Maschinenbau*, Vol. 8, 1929, pages 772–773.

[15] H. Kummer. Die Erichsen-Blechprüfung. *Maschinenbau*, Vol. 6, 1927, page 764.

[16] M. Schmidt. Die Prüfung von Tiefziehblech. *Archiv für das Eisenhüttenwesen*, Vol. 3, Sept. 1929, pages 213–222; *Stahl und Eisen*, Vol. 49, Nov. 21, 1929, pages 1695–1696; *Iron & Coal Trades Review*, Vol. 119, Dec. 1929, page 913; *Metal Stampings*, Vol. 3, Feb. 1930, pages 117–118.

[17] W. Aumann. *Maschinenbau*, Vol. 7, 1928, pages 105–110.

[18] G. R. Fischer. Sonder-Prüfeinrichtungen, Prüfverfahren zur Wertung von Ziehblechen. *A. E. G. Mitteilungen*, Vol. 1, Oct. 1927, pages 419–420.

[19] K. Daeves. Die Wirklichen Beziehungen zwischen der Blechdicke und Erichsentiefung. *Stahl und Eisen*, Vol. 50, Oct. 23, 1930, page 1501.

[20] C. L. Eksergian. Plastic Behavior of Metal in Drawing. *Transactions American Society for Mechanical Engineers*, Vol. 48, 1926, pages 609–645.

[21] T. E. Green. Cupping Tests. *Mechanical World*, Vol. 89, 1931, pages 245–246.

[22] R. J. Anderson. The Cupping Test for Aluminum Sheet. *Metal Industry*, London, Vol. 37, 1930, pages 265–268.

[23] I. Fetschenko-Tschopiwiski & M. Opalko. Flow Phenomenas in Deep Drawing of Sheet Metal. Abstract from *Zeitschrift des Oberschlesischen Berg- und Hüttenmannischen Vereins; Metal Stampings*, Nov. 1930, pages 1027–1029, Dec. 1930, pages 1115, 1116, 1125.

[24] G. R. Fischer. Sonder-Prüfeinrichtungen, Prüfverfahren zur Wertung von Ziehblechen. *A. E. G. Mitteilungen*, July 1929, pages 483–486.

[25] Copper and Copper Alloys—Cast & Wrought. *Report of Committee B5, American Society for Testing Materials*, Preprint for June 1931 meeting. 7 pages.

[26] J. S. Adelson. Physical Values Assist in Specifying Cold Strip. *Steel*, Vol. 88, March 5, 1931, pages 50, 53; March 19, 1931, pages 42–43, 46.

[27] E. S. Lawrence. Chapter II. Manufacture of Steel Sheets. Penton Publishing Co., 1930.

[28] E. Ackermann. Das Ziehen von Hohl Körpern aus Feinblechen unter besonderer Berücksichtigung der Blechhaltereinflüsse. *Dr. Ing. Dissertation, Technische Hochschule, Dresden*, 1931.

J. Blume. Ermittelung der Ziehfähigkeit von Tiefstanzblechen. *Metallbörse*, Vol. 12, 1922, pages 1945–1946.

H. Brasch. Das Ziehen unregelmässig geformter Hohlkörper. *Verein deutscher Ingenieure Forschungsarbeiten*, Heft 268.

R. Casaud. Les essais d'emboutessage des tôles. *Aciers Spéciaux, Métaux et Alliages*, Jan. 1930, pages 6–14.

E. V. Crane. Metal Working in Power Presses. *American Institute Mining & Metallurgical Engineers*, Preprint, Feb. 1931, 31 pages. Strain-Hardening of Plastic Metals. *Iron Age*, Vol. 128, July 23, 1931, pages 250–253; Aug. 20, 1931, pages 498–499, 543; Sept. 3, 1931, pages 626–630; Oct. 1, 1931, pages 872–875.

H. Draeger. Einfluss der Abrundung beim Ziehen von Hohlkörpern aus dünnen Blechen. *Verein deutscher Ingenieure, Bericht über Betreibswissenschaftliche Arbeiten*, Band 2, 1929, pages 1–19.

F. Fischer. Oberflächendehnung, Faltenbildung und Verhinderung beim Hohlgefässziehen. *Dissertation*, Stuttgart, April 1927, 64 pages

F. D. Jones. Die Making and Die Design. The Industrial Press, 1923.

Kaczmarek. Die moderne Stanzerei. 2nd edition. Verlag Julius Springer, Berlin, 1925; *Maschinenbau*, Vol. 6, 1927, page 764.

A. T. Kathner & P Damiron. La fabrication et les traitements thermiques de la tôle pour l'industrie automobile. *Revue de Métallurgie*, Vol. 27, Nov. 1930, pages 615–629.

O. Kühner. Verwendung von Druckluft-faltenhaltern bei Verarbeitung von Nichteisen Metalle. *Zeitschrift für Metallkunde*, Vol. 22, 1930, pages 190–193.

Kurrein. Werkzeuge und Arbeitsverfahren der Presse. Verlag Julius Springer, Berlin, 1926

E. Marke. Die Bedeutung der ersten Glühung für Qualitätsfeinbleche, der Einfluss auf die Erichsen Tiefung und das Gefüge. *Archiv für Eisenhüttenwesen*, Vol. 2, 1929, pages 851–865.

Musiol. Rechnerische und Zeichrechnerische Methode der Zuschnittsermittlung in der Ziehpress Technik. Verlag L. Stroll, Jr., Leipzig, 1908. Die Kalibrierung der Ziehwerkzeuge. *Stahl und Eisen*, Vol. 27, 1907, pages 477–482, 513–520, 551–558.

L. Persoz. Essai des tôles à la perforation. *Revue de Métallurgie*, Vol. 8, Aug. 1911, pages 606–612; *Aciers Spéciaux, Métaux et Alliages*, Vol. 3, 1928, page 302.

E. Pitois. Nouvelle machine pour l'essai des tôles. *La Technique Aeronautique*, 1924, page 306.

E. Ruhrmann. Bördlen und Ziehen in der Blecharbeitungs-technik *Verein deutscher Ingenieure Forschungsarbeiten*, Heft 277.

G. Sachs. Untersuchungen über Tiefziehen. *Mitteilungen der deutschen Materialprüfungsanstalten*. Sonderheft XVI. 1931, pages 11–37. Also in Sachs, Spanlose Formung der Metalle. Verlag Julius Springer, Berlin, 1931, pages 11–37.

E. Siebel. Das Bildsame Verhalten der Metalle Beim Ziehen. *Stahl und Eisen*, Vol. 47, 1927, pages 1340–1341. Erfassung des Arbeitsbedarfs bei Technologischen Formgebungsprozessen. *Metallwirtschaft*, Vol. 8, Part 2, July 26, 1929, pages 724–726.

E. Siebel & A. Pomp. Ueber den Kraftverlauf beim Tiefziehen und bei der Tiefungsprüfung. *Mitteilungen aus dem Kaiser Wilhelm Institut für Eisenforschung*, Vol. 11, 1929, pages 139–154.

W. Sellin. Die Berechnung von Ziehwerkzeugen. *Maschinenbau*, Vol. 3, 1923–4, pages 229–235. Einfache rechnerische Ermittlung des Zuschnitts in der Ziehtechnik bei Berücksichtigung der Blechdehnung. *Maschinenbau*, Vol. 3, 1923–4, pages 482–484. Die Ziehtechnik in der Blechbearbeitung. Verlag Julius Springer, Berlin, 1926. Ueber den Einfluss der Rundung von Ziehring und Ziehstempel an Werkzeugen zum Ziehen von Blechhohlkörpern auf die Ziehtiefe im Anschlag. *Verein deutscher Ingenieure, Berichte über Betriebswissenschafttechnische Arbeiten*, Band 3, 1930, pages 18–35.

M. Sommer. Versuche über das Ziehen von Hohlkörpern. *Verein deutscher Ingenieure Forschungsarbeiten*, Heft 286; *Maschinenbau*, Vol. 4, 1925, pages 1171–1178.

The following papers relating to the general subject of this correlated abstract were presented at the meeting of the American Society for Steel Treating, September 21, to 25, 1931, and will appear later in the publications of that society.

E. S. Lawrence. Comparison of Sheet and Strip Steels for All Difficult Stampings.

E. V. Crane. Plastic Drawing of Sheet Steel into Strips.

H. T. Morton & I. A. Rummler. Thin Strip Steel for Deep Drawing.

W. F. McGarrity & H. V. Anderson. Effect of Normalizing upon the Grain Structure and Physical Properties of Automobile Sheet Steel.

M. Reswick. Lubricants Used in Deep Drawing of Sheet Steel

J. Winlock & A. E. Lavergne. Some Effects of the Amount and Rate of Deformation on a Low Carbon Strip Steel.

T. Dockray. The Evaluation of the Drawing Quality of Extra Deep Drawing Sheets.

[29] W. A. Straw, M. D. Helfrick & C. R. Fischrupp. Forming Properties of Thin Sheets of Some Non-Ferrous Metals. Technical Publication No. 406 *Institute of Metals Division, American Institute of Mining & Metallurgical Engineers*, 1931, 14 pages.

[30] C. Jovignot. Méthode et appareil d'essai donnant le coefficient d'extension et la charge de rupture des produits métallurgiques en feuilles. *Revue de Métallurgie*, Vol. 27, 1930, pages 443–448.

[31] E. Siebel & A. Pomp. Ueber den Kraftverlauf beim Tiefziehen und bei der Tiefungsprüfung. *Mitteilungen aus dem Kaiser Wilhelm Institut für Eisenforschung*, Vol. 11, 1929, pages 139–154. Die Prüfung von Feinblechen durch den Tiefzieh-Weitungsversuch. *Mitteilungen aus dem Kaiser Wilhelm Institut für Eisenforschung*, Vol. 12, 1930, pages 115–125. Ein neues Prüfverfahren für Feinbleche. *Mitteilungen aus dem Kaiser Wilhelm Institut für Eisenforschung*, Vol. 11, 1929, page 287.

E. Siebel. Ein neues Prüfverfahren für Feinbleche. *Stahl und Eisen*, Vol. 49, 1929, pages 1866–1868. See also *Iron & Coal Trades Review*, Vol. 120, Feb. 28, 1930, page 378.

[32] J. Cournot. Sur une nouvelle méthode d'essai des tôles à l'emboutissage. *Revue de Métallurgie*, Vol. 28, May 1931, pages 254–258.

[33] G. Sachs. Ein neues Prüfgerät für Tiefziehlbeche (Keil Ziehversuche). *Metallwirtschaft*, Vol. 9, Mar. 7, 1930, pages 213–218. *Mitteilungen aus der deutschen Materialprüfungsanstalten*—Sonderheft XIII, 1930, pages 80–85 Untersuchungen über Tiefziehen. *Mitteilungen aus der deutschen Materialprüfungsanstalten*, Sonderheft XVI. 1931, pages 11–37. Also in Sachs —Spanlose Formung der Metalle. Verlag Julius Springer, Berlin, 1931, pages 11–37.

[34] H. L. Miller. Specialty Oils. *Monthly Review, American Electroplaters Society*, Vol. 18, May 1931, page 51.

[35] E. Houdremont. Die rostfreien Stahle, ihre Eigenschaften und Herstellung. *Kruppsche Monatshefte*, Vol. 11, 1930, pages 270–286.

[36] E. V. Crane. Metal Working in Power Presses. *American Institute of Mining & Metallurgical Engineers*, Preprint, Feb. 1931, 31 pages; Aug. 20, 1931, pages 498–499, 543; Sept. 3, 1931, pages 626–630; Oct. 1, 1931, pages 872–872.

[37] N. Dwidenkow & K. Jurjew. Die Streckgrenze im Schlagversuch *First Communications of the New International Association for the Testing of Materials*. Group A. Zurich, 1930, pages 231–236.

[38] C. H. Mathewson, C. S. Trewin & W. H. Finkelday. Some Properties and Applications of Rolled Zinc Strip and Drawn Zinc Rod. *Transactions American Institute of Mining & Metallurgical Engineers*, Vol. 64, 1921, pages 305–377.

[39] Republic Research Corp. X-ray Control in Cold Rolling Steel Sheets and Strip. *Iron Age*, Vol. 126, Oct. 30, 1931, pages 1221–1223.

A. Phillips & G. Edmunds. An X-ray Study of Copper Which Showed Directional Properties on Cupping. *Proceedings American Society for Testing Materials*, Vol. 29, II, 1929, pages 438–447. Causes of Tip Formation on Deep Drawn Shells. *Metal Stampings*, Vol. 2, Sept. 1929, pages 703–760.

A. Phillips & E. S. Bunn. Directional Properties in Cold Rolled and Annealed Copper. Technical Publication No. 413, *American Institute of Mining & Metallurgical Engineers*, 1931. 18 pages. See also abstracts in *Metallurgist*, June 26, 1931, pages 89–91.

[40] F. Wever. Texture of Metals After Cold Deformation. *American Institute of Mining & Metallurgical Engineers*, Preprint, Feb. 1931, 25 pages. See also *Mitteilungen aus dem Kaiser Wilhelm Institut für Eisenforschung*, Vol. 5, 1924, pages 69–77.

[41] G. Sachs & G. Kurdgumow. Walz-und Rekristallisations Texture von Eisenblech. *Mitteilungen aus der deutschen Materialprüfungsanstalten*, Sonderheft 13, 1930, page 67–70.

F. Von Göler & G. Sachs. Untersuchungen an Kupfer und Messing. *Zeitschrift für Metallkunde*, Vol. 20, 1928, pages 202–208.

Effect of Molybdenum on Graphitization of White Cast Iron*

BY W. H. JENNINGS, JR.† AND E. L. HENDERSON‡

INTRODUCTION

THE investigation reported in this paper was undertaken with the object of determining the quantitative effect of molybdenum upon the rate of graphitization of white cast iron.

A search of the literature reveals very little information concerning the effect of this element on graphitization rates as applied to the white cast variety with its lower silicon content in comparison to gray cast iron. Practically all the experimental reports available are concerned with gray cast iron.

E. K. Smith and H. C. Aufderhaar[1] prepared 40 melts using a gray cast iron base and a molybdenum content of 0.66, 1.77 and 3.10%. Increasing molybdenum showed a tendency for decreasing graphitic carbon and approached the carbon condition of white cast iron. No strictly quantitative annealing tests were made. The pearlitic structure indicated a refinement and the general grain growth was inhibited. They attribute this latter condition to the presence of molybdenum in the form of a solid solution in ferrite.

Musatti and Calbiani[2] made a complete study of the effect of molybdenum on the properties of malleable iron. This was prepared from a special cast iron with a carbon content near that usually found in white cast iron but with a silicon content from 2 to 3 times greater than that of the usual white cast variety. While it is interesting to note that they obtained an improvement of the physical properties through molybdenum additions, no definite conclusions may be drawn in connection with the ultimate results of the investigation that are reported in this paper.

The work of Coonan[3] approaches nearer to the field of investigation, that is reported in this paper, than any other report that is available. However, Coonan's work covers a molybdenum content no higher than 1%. He annealed sample bars, with a molybdenum content ranging from 0 to 1%, for an overall period of 140 hours at a temperature of 1550° F. (840° C.) This included the time of annealing and cooling. No information is given concerning the rate of cooling nor the time at the maximum temperature. The composition of the cast iron base which was employed in alloying with the molybdenum was comparable to the composition of the usual white cast iron. His results show that there is a decided increase in yield point and in tensile strength but the ductility reaches a maximum with 0.5% molybdenum and decreases again as the molybdenum content is increased to 1%.

Coonan did not determine the conditions for the destruction of the pearlitic portion of his alloys and all his specimens, which contain molybdenum, show the presence of pearlite. His conclusion that molybdenum retards the decomposition of massive cementite into temper carbon is justified from an examination of the photomicrographs that were submitted.

* This paper is based upon the content of a thesis submitted to the Graduate Faculty of Iowa State College, Ames, by the junior author in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

† Assistant Professor of Physical Chemistry, Iowa State College.

‡ Instructor of Chemistry and Metallography, Iowa State College.

[1] E. K. Smith & H. C. Aufderhaar. *Iron Age*, Vol. 124, 1929, page 1507.

[2] Musatti & Calbiani. *La Metallurgia Italiana*, Vol. 23, 1930, page 649.

[3] F. L. Coonan. *Heat Treating & Forging*, Vol. 15, 1929, page 1561.

EXPERIMENTAL METHODS AND DATA

A. Materials Used

The materials employed in the preparation of the alloys used in this investigation are listed as follows:

1. Ferro-molybdenum containing an average of 63% molybdenum and 1.13% carbon.
2. Ferro-silicon containing an average of 46% silicon.
3. Crushed and powdered graphite.
4. Commercial white cast iron test bars with the following chemical composition.

Table 1.

Element	Weight, % I	II
Carbon	2.58	2.63
Silicon	0.78	0.78
Manganese	0.19	0.21
Sulphur	0.034	0.032
Phosphorus	0.154	0.155

The analytical methods employed were, in general, those that have been recommended by the American Society for Testing Materials. Some alterations were made, particularly in the case of sulphur. The iron was removed by precipitation with sodium carbonate solution and the sulphur was precipitated as barium sulphate by the addition of barium chloride solution to the acidified filtrate.

The carbon determination was made by direct combustion in a stream of oxygen, using an Ascarite tower as the absorbent mechanism for the carbon dioxide. The sodium bismuthate method was employed for the manganese and the alkali-acid titration method for the phosphorus. The nitric-sulphuric acid dehydration method was employed for the determination of the silicon. When available, Bureau of Standards samples were analyzed in conjunction with the other analyses to serve as a check on the other determinations.

B. Preparation of the Alloys

Seven series of alloys were prepared from the commercial cast iron base with a molybdenum content ranging from 1 to 5%. The cast iron was melted in a plumbago crucible by means of a 35 kv. induction furnace. After the additions of the required quantities of ferro-molybdenum, ferro-silicon and powdered graphite to the molten cast iron, the alloys were cast into sand molds at a pouring temperature of approximately 2460° F. (1350° C.) as determined by a Leeds and Northrup optical pyrometer. The alloys were allowed to cool to room temperature in the molds before exposure to the air. Immediately before pouring, the molten alloys were stirred with an Armco iron rod to insure uniform composition.

After cooling, the bars were broken into convenient lengths of approximately 1 inch. The diameter of the bars was $^5/_8$ inch. One specimen of about 6 inches was reserved from each melt for chemical analysis. The 1 inch pieces were reserved for subsequent heat treatment and microscopical examina-

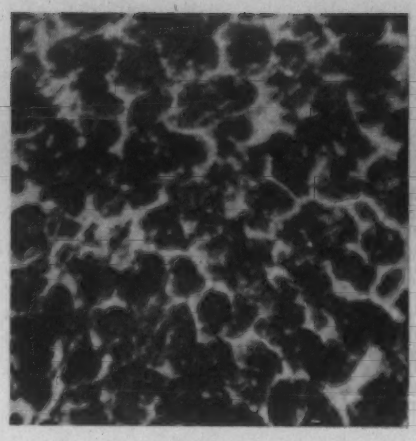


Fig. 1. Cast Iron with 1% Mo. Mag. 125×. As Cast.

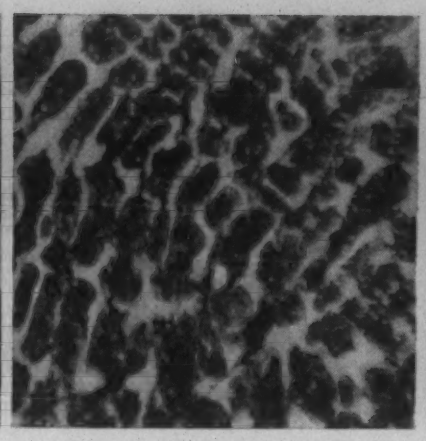


Fig. 2. Cast Iron with 4% Mo. Mag. 125×. As Cast.

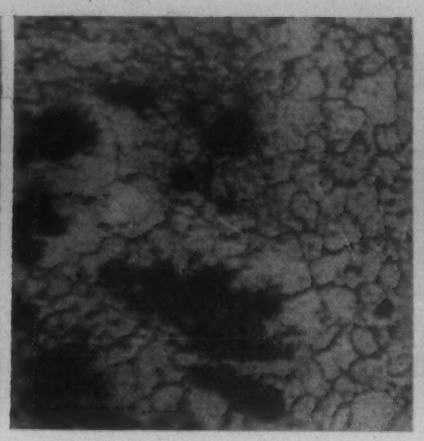


Fig. 3. Cast Iron with 1% Mo. Mag. 150×. 74 hrs. at 1700° F. 124 hrs. at 1300° F.

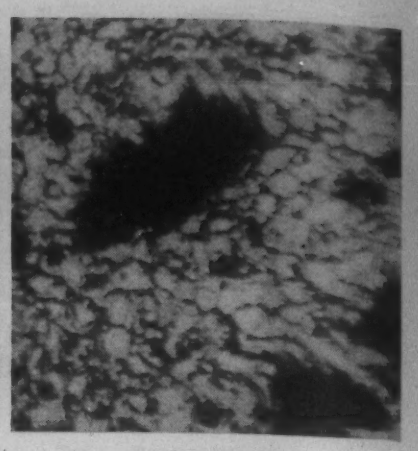


Fig. 4. Cast Iron with 2% Mo. Mag. 150×. 89 hrs. at 1700° F. 163 hrs. at 1300° F.

tion. The fracture was from gray-white to white and many specimens showed a slight segregation toward the center of the piece.

C. Chemical Composition of the Alloys

The composition of the alloys is given in Table 2. The composition of the commercial white cast iron has been given in Table 1. The molybdenum was determined gravimetrically as lead molybdate. The other constituents were determined by the same methods as were employed for the commercial white cast iron.

Table 2.

Melt No.	Weight, % Mo	C	Si	Mn	S	P
S-1-1	0.92	2.79	0.78	0.21	0.031	0.148
	0.92	2.78	0.78	0.20	0.035	0.149
S-12-1	0.93	2.63	0.76	0.18	...	0.149
	0.93	2.70	0.77	0.20	...	0.150
S-6-2	1.84	2.51	0.79	0.19	0.036	0.151
	1.86	2.52	0.82	0.21	0.038	0.151
S-11-2	1.85	2.62	0.86	0.17	...	0.150
	1.86	2.63	0.86	0.20	...	0.151
S-7-3	3.17	2.63	0.66	0.18	0.038	0.149
	2.98	2.63	0.63	0.19	0.036	0.151
S-13-4	4.09	2.55	0.65	0.22	0.034	0.149
	4.11	2.61	0.65	0.19	0.036	0.149
S-14-5	4.95	2.58	0.61	0.21	0.033	0.150
	4.96	2.63	0.62	0.19	0.032	0.151

The molybdenum alloys were all extremely hard as cast and a great deal of difficulty was experienced in preparing them for chemical analysis.

D. Heat Treatment

As a preliminary operation, 1 inch samples of each composition were placed in cast iron pipe containers, capped at 1 end, and introduced into a Hump electric annealing furnace at 1710° F. (930° C). Gas carbon of about 20 mesh was employed as the packing material. This served to partially check the decarburization of the samples that were held at the elevated temperatures for long periods. In spite of these precautions, appreciable decarburization was observed at the surface of the samples. A container, with a sample of each composition, was removed at the following intervals:

½ hour	10 hours	48 hours
74 hours	100 hours	257 hours

In this preliminary treatment the samples were removed from the furnace to the air and allowed to cool in the carbon pack. In the final treatment they were allowed to cool in the furnace to a temperature of 840° F. (450° C.) before removal to the air for the cooling to room temperature.

Upon removal at the stated intervals, the samples were prepared for microscopical examination and the progress of the decomposition of the massive cementite was observed. Nital was employed as the etching reagent. In this manner, the time required for the primary stage of graphitization was determined within the limits of + or − 5 hours. At least 4 samples of each composition were then given the predetermined heat treatment.

A similar procedure was undertaken to determine the minimum time required for the secondary stage of graphitization at 1300° F. (705° C.). The samples, which had previously been given the required treatment at 1710° F. (930°C.) were placed in the furnace at this temperature and maintained for ½ hour. The furnace was then cooled to 1300° F. (705° C.) at a controlled rate of 33.3° F. per hour. This temperature was maintained and samples were removed at 24-hour intervals and examined microscopically to determine the progress of the secondary stage of decomposition. After the optimum time had been found, all samples were returned to the furnace at the proper intervals to insure that every sample of the same composition would have the identical time at 1300° F. (705° C.). When the proper time had elapsed, the furnace was cooled under control to 840° F. (450° C.) at the rate of 12° F. per hour. The samples were then removed from the furnace and air cooled in the carbon pack.

The samples were then ready for final microscopical examination and photographic study.

PRESENTATION OF RESULTS

Table 3 shows the optimum time required for the completion of the primary and secondary stages of graphitization. The molybdenum contents are given in round numbers.

Table 3.

Alloy No.	Weight, % Mo	Time for Complete Graphitization At 1700° F. (930° C.)	At 1300° F. (705° C.)
S-1-1	1	75 to 80 hrs.	120 to 125 hrs.
S-12-1	1	75 to 80 hrs.	120 to 125 hrs.
S-6-2	2	90 to 100 hrs.	160 to 165 hrs.
S-11-2	2	90 to 100 hrs.	160 to 165 hrs.
S-7-3	3	150 to 155 hrs.	195 to 200 hrs.
S-13-4	4	200 to 205 hrs.	245 to 250 hrs.
S-14-5	5	Incomp. 255 hrs.	Incomp. 250 hrs.
Com. Cast	0	60 to 65 hrs.	100 to 105 hrs.

The results tabulated in Table 3 were obtained by examination of the samples under the microscope and by a study of the photomicrographs. The specimens were photographed at intermediate stages of graphitization and of the completely graphitized alloys. A few of the photomicrographs are reproduced in Figs. 1 to 8. Only the 1 and 4% molybdenum alloys are illustrated in the "As Cast" condition. Final results of the optimum heat treatment are shown for each molybdenum composition and for the commercial cast iron. The captions for each photomicrograph are self explanatory. These show that the molybdenum serves to refine the grain structure in comparison to the completely graphitized sample which contained no molybdenum. This may partially explain the increased hardness and toughness of the molybdenum containing alloys.

The alloys, containing from 1 to 4% molybdenum, were successfully graphitized in the time indicated under Table 3. The 5% alloy was only partially graphitized at both stages

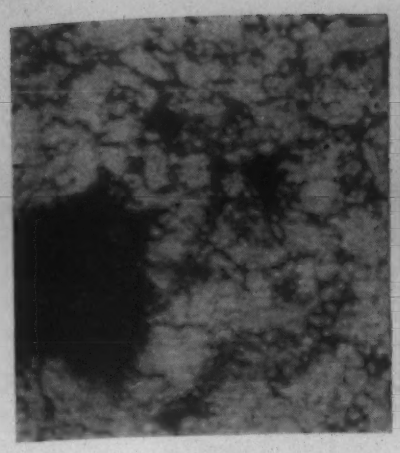


Fig. 5. Cast Iron with 3% Mo. Mag. 150×. 151 hrs. at 1700° F. 196 hrs. at 1300° F.

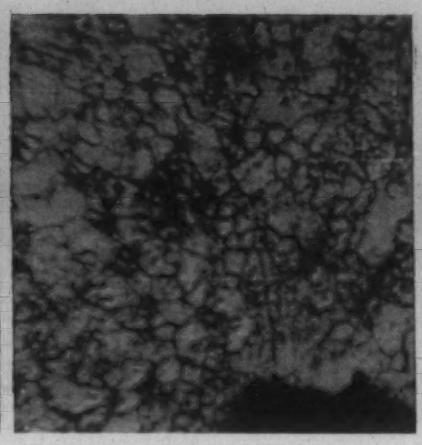


Fig. 6. Cast Iron with 4% Mo. Mag. 150×. 202 hrs. at 1700° F. 247 hrs. at 1300° F.

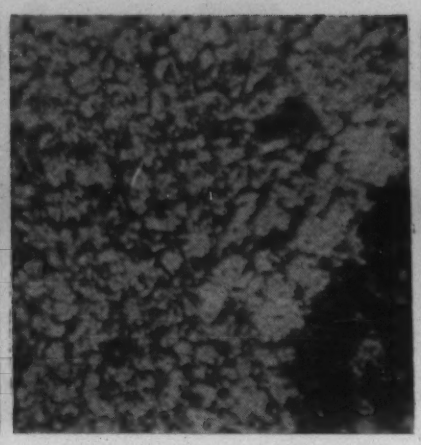


Fig. 7. Cast Iron with 5% Mo. Mag. 150×. 252 hrs. at 1700° F. 247 hrs. at 1300° F.

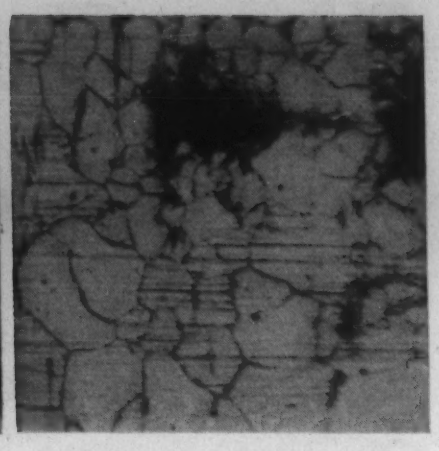


Fig. 8. Commercial Cast Iron. Mag. 150×. 65 hrs. at 1700° F. 100 hrs. at 1300° F.

for the periods of heat treatment that are indicated. It seemed that no information of value would result from a more prolonged heat treatment above 255 hours.

It has been observed that these alloys were hard and tough as cast. The hardness could be partially destroyed merely by holding the samples at 1710° F. (930° C.) for 1 hour and air cooling in the carbon pack. However, these properties could be improved by quenching in cold water from the above temperature rather than cooling in air. A martinsitic structure was in evidence after such treatment.

SOME THEORETICAL CONSIDERATIONS

The question may arise as to the probability of predicting the effect of elements in general and molybdenum in particular upon the graphitization of white cast iron. Several theories for the mechanism of graphitization have been proposed. Without implying acceptance of any particular theory, we may safely assume the following fundamental equation as the final expression:

$$Fe_3C \rightleftarrows 3Fe + C \qquad (1)$$

For actual operating conditions involved in the graphitization of white cast iron, the following modified form of the free energy equation may be applied:

$$-\Delta F = RT\left[\ln K - \ln \frac{({}^{a}'C)\,({}^{a}'Fe)^3}{({}^{a}'Fe_3C)}\right] \qquad (2)$$

The constant (K) refers to equilibrium conditions. In the pure iron-carbon alloys the activities of the carbon, iron and iron carbide may be assumed to be unity and the second term of equation (2) becomes zero. However, different conditions would result should an added element affect the activity of iron or iron carbide. The activity of the pure carbon is generally assumed to be independent of the alloying elements.

If an added element lowers the activity of the iron, the $-\Delta F$ would become more positive and the decomposition of Fe_3C would be favored according to equation (1). This prediction is in accord with the known positive effect of silicon on graphitization. Silicon dissolves in iron to form solid solutions.

Again should an element exhibit a tendency to associate with the carbide and affect its activity, it would be expected that $-\Delta F$ would become less positive. The tendency for the decomposition of the iron carbide, according to equation (1), would be less and the reaction would eventually proceed to the left and favor the formation of the carbide when $-\Delta F$ has become negative. Chromium is known to form carbides rather easily and we should expect that this element would adversely affect the graphitization process. This prediction has been confirmed by the work of Foulke[4] in this laboratory on the effect of chromium on the graphitization of white cast iron.

In general, those elements which form solid solution with the iron have been found to promote graphitization, due to the lowering of the activity of the iron according to the explanation just suggested. Those elements that show a tendency for carbide formation are known to inhibit or completely stop the mechanism of graphitization.

This paper has shown that molybdenum decreases the rate of graphitization. However, it is not completely stopped until the molybdenum content at least exceeds 5%. According to Takei and Murakami,[5] pure iron-molybdenum alloys form solid solutions within the ranges employed in this investigation. But from the results herein reported, using commercial white cast iron as the base in preparing the molybdenum alloys, it seems that the molybdenum is for the most part associated with the carbide. Little is known concerning the nature of the molybdenum-carbon alloys and the ternary iron-molybdenum-carbon diagram has not been determined.

If the molybdenum is wholly or in part associated with the carbide, $-\Delta F$ would become less positive and the tendency for the decomposition of the Fe_3C, according to equation (1), would be less. This prediction has been confirmed by the results reported in this paper.

CONCLUSIONS AND SUMMARY

A study has been made of the quantitative effect of molybdenum upon the decomposition of iron carbide in the malleabilization process for white cast iron. Molybdenum contents from 1 to 5% were employed.

It has been shown that the rates for both the secondary and primary stages are almost inversely proportional to the molybdenum content within the ranges from 1 to 5%. The secondary stage is practically negligible for the 5% alloy over a time interval of 250 hours.

Definite time requirements for both stages have been determined for each molybdenum content. These results are shown in tables in their proper sequence.

It has been shown that the presence of molybdenum results in a positive refinement of the grain structure.

No attempt has been made to correlate the physical properties of the alloys with the chemical composition except through the qualitative observations that were made during the breaking, grinding and polishing of the samples. Such observations have led to the belief that molybdenum imparts hardness, toughness and tensile strength to the malleableized iron. This phase of the problem will be investigated and reported in a subsequent paper.

The general free energy equation has been applied in an attempt to base a theoretical prediction of the effects of selected elements on the rates of graphitization of the commercial white cast iron. Experimental evidence offers confirmation to these theoretical predictions.

[4] C. D. Foulke. The Effect of Chromium on White Cast Iron *Unpublished Thesis, Iowa State College Library*, Ames, 1930.

[5] Takei & Murakami. *Transactions American Society for Steel Treating*, Vol. 16, 1929, page 339.

Shot Gun Explosion Mystery Solved by Metallography

BY OSCAR E. HARDER*

SOUTHERN Minnesota is the scene of the explosion and the time is about fifteen minutes after the opening of the duck shooting season in the fall. The leading man is a recent college athlete and the gun is one of the best of the type to be had in the market.

The effects of the explosion on the gun are shown in Fig. 1. The right hand barrel of the gun was blown off, thrown some 75 feet away and in the course of its travel passed over the top of a nearby telephone post. As may be expected, the man behind the gun did not escape injury, but was fortunate

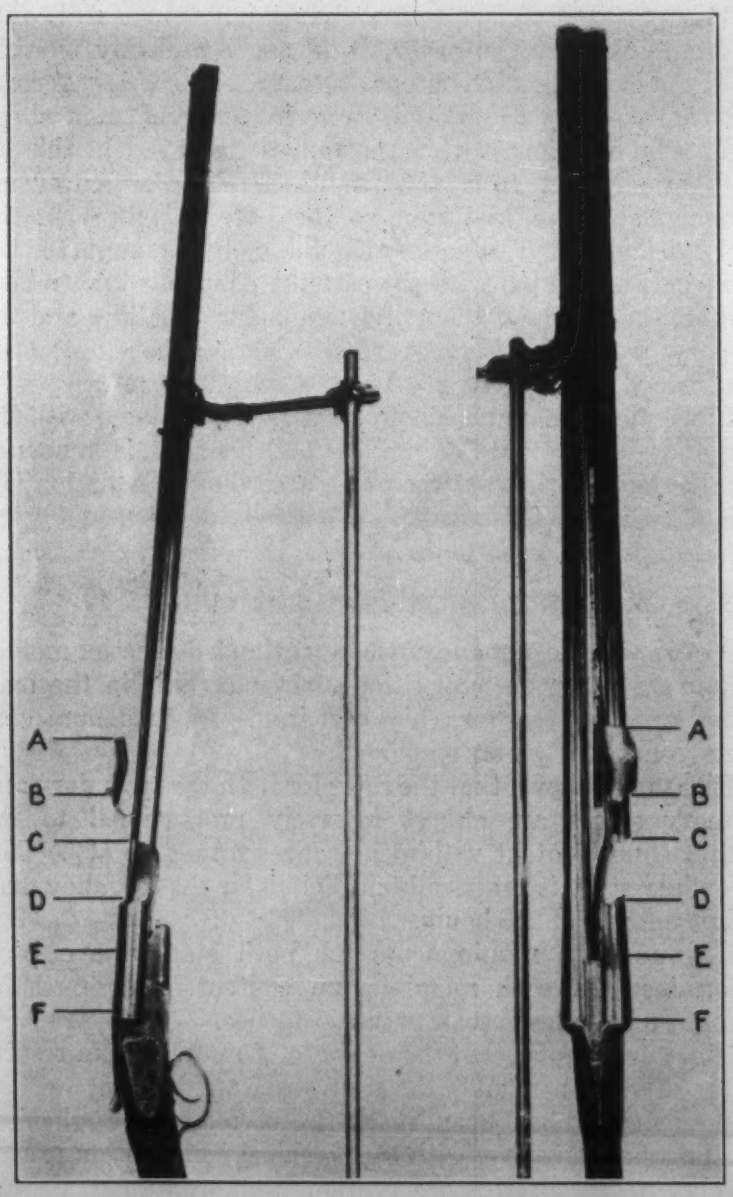


Fig. 1. Two Views of Gun Showing Location and Effect of the Explosion.

in receiving rather slight damage considering the character of the accident, the only serious injury resulting in the loss of the little finger from one hand. Some weeks later the gun was brought to the writer with a request that he examine it and try to find out the cause of the explosion.

* Assistant Director Battelle Memorial Institute, formerly Professor of Metallography, University of Minnesota. The work reported was done at the University.

A visual examination showed the following significant points of information. At point E on the inside of the gun barrel there is indication of a fracture previous to the time of the explosion, which is shown by the presence of rust in the fracture. The structure of the fracture at points D and A was coarse, especially on the inside part of the barrel. The structure of the fracture at D is shown at a magnification of about two diameters in Fig. 2, and a section of the coarsest structure is shown at a magnification of about 8 diameters in Fig. 3. The structure at point C and from C to B was shown to be much finer and to be of what is known as fibrous or tough structure.

One particularly significant point was what appeared to be a piece of brass embedded in the gun barrel at about point C. The size of this specimen, magnified about 2 diameters, can be seen from Fig. 4 and it will be noted that this area of supposed brass is quite small.

The possible explanations of this explosion seem to include the following: (1) defective material in the gun barrel; (2) an unusually high charge of powder in the shell used; and

BENVENUTO CELLINI wrote, some 400 years ago, "It is true that the great delight I took in hunting bid fair to withdraw me from my art and studies; yet in another way it gave me more than it deprived me of, seeing that each time I went shooting, I returned with greatly better health, since the open air was a benefit to my constitution. My natural temperament was melancholy, and while I was taking these amusements, my heart leapt up with joy, and I found that I could work better and with far greater mastery than when I spent my whole time in study and manual labor. In this way my gun, at the end, stood me more profit than loss." Since the hunting season is upon us, the above, and the metallurgical detective story below, may be timely in urging us to go hunting, if we need any urge, and to take proper precautions when we do it.

(3) that the gun barrel was closed by a shell of smaller gage in the barrel ahead of the one in the magazine.

The structure of the barrel at points C and D has been mentioned previously. These were examined microscopically and the grain size at point D is shown in Fig. 5. The white areas are the grain boundaries. This coarsened structure was produced by heating the steel to too high a temperature. This is to be contrasted with the grain size at point C which is shown in Fig. 6.

An intermediate grain size is shown in Fig. 7 which represents the structure on the outside of the barrel at F. This same structure is shown in a higher magnification in Fig. 8.

The inside of the gun barrel has been shown to have a coarser structure than the outside, and, further, the structure is coarse only throughout and near to the region of brazing. This seems to indicate that in the brazing operation the

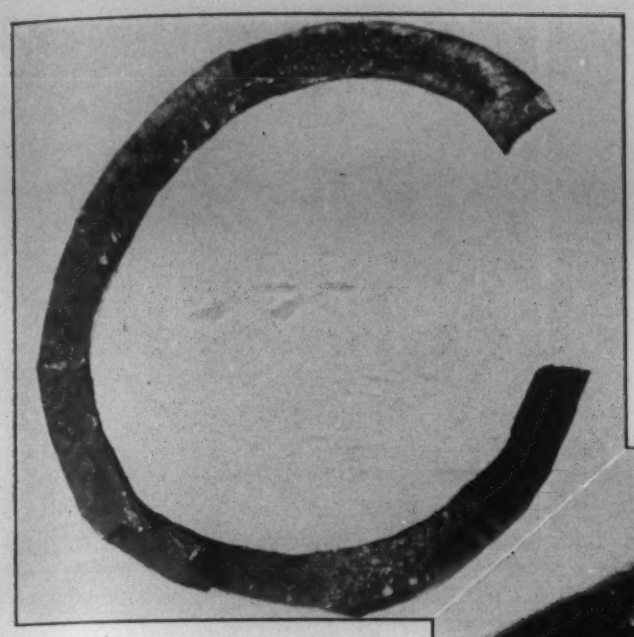


Fig. 2. Fracture at D. ×2.

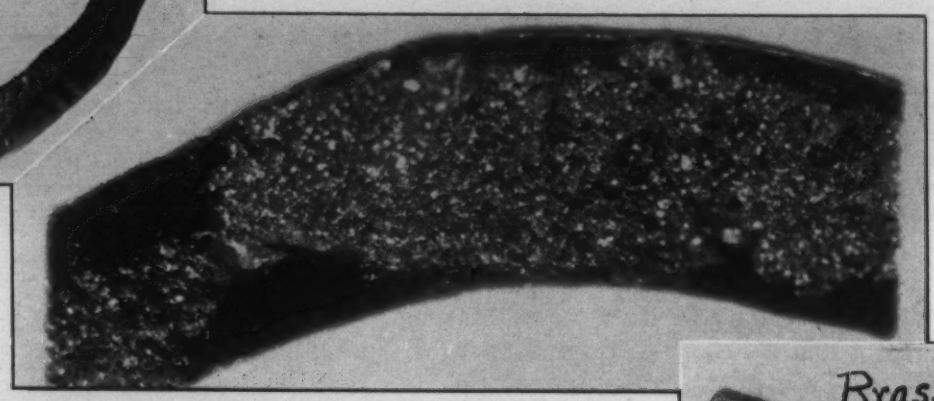


Fig. 3. Portion of Coarse Structure in Fracture at D. ×8.

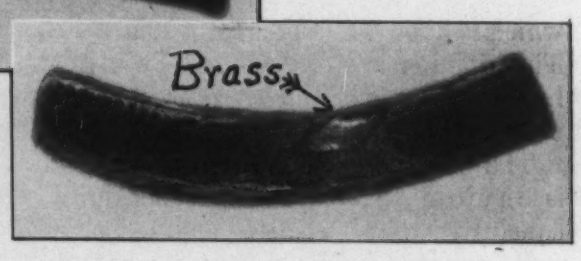


Fig. 4. Section of Barrel Showing Embedded Brass. ×2.

barrel has been heated to an exceedingly high temperature and as a result the grain has been coarsened and weakened and the fracture on the inside of the barrel at point E seems to have been a result of this weakening of the barrel.

The position of this fracture is shown in Fig. 9. The effect of the fracture on the shell is shown in Fig. 10.

This survey seems to show that undoubtedly the steel in this gun barrel has been overheated, probably in the heating for the brazing operation, and is therefore not of as good quality as it should have been.

Further investigation, however, seems to show that the explosion of the gun barrel is not due to the character of the steel, but that the character of the steel simply modified the effect of the explosion, and that the explosion was due to an entirely different cause.

The position of the explosion seemed to suggest the possibility of the shell of smaller bore having been in the barrel. The small particle of brass found at point C also indicated that this probably resulted from an impact of the shell against the barrel. It was therefore necessary in order to establish this point to show that the embedded piece of brass was of the same general character as cartridge brass. A microscopic examination of the embedded brass revealed the structure shown in Fig. 11.

Naturally the structure of the brass would be seriously modified by the impact of the explosion which embedded it in the gun barrel. In order to obtain this material in a normal structure it was annealed over night at a temperature of about 600° C., which is known to be the proper temperature for annealing cold worked or mechanically deformed brass, and then it was rephotographed. The structure at 1000 diameters is shown in Fig. 12. This is found to be the typical structure of brass of the kind used in gun cartridges,

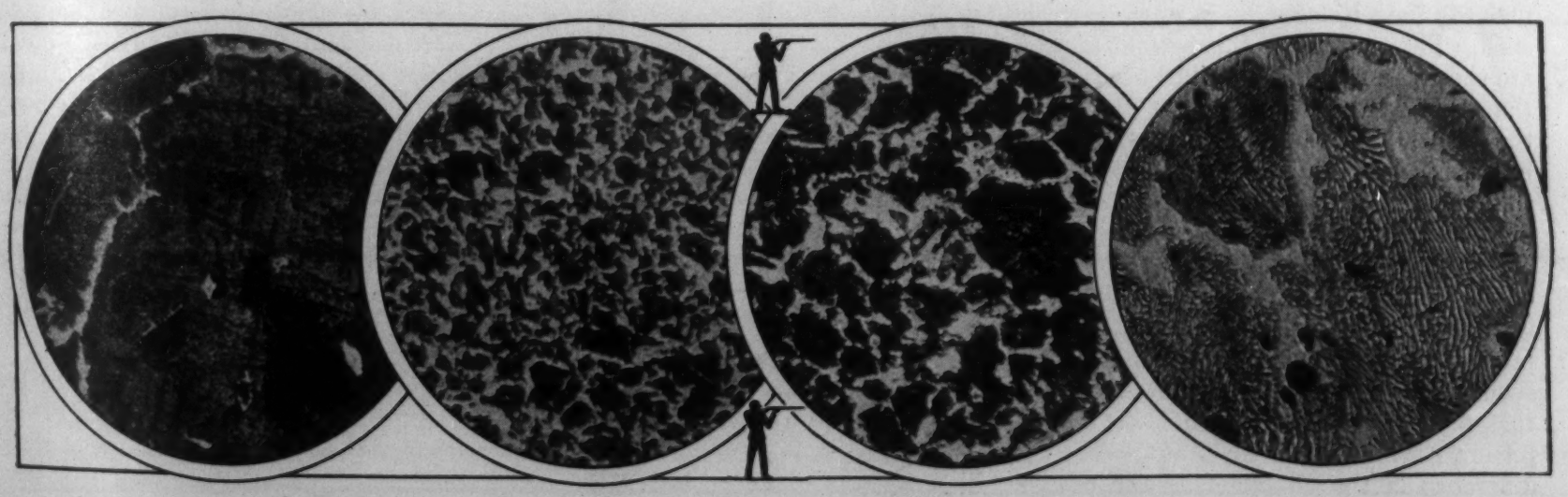


Fig. 5. Photomicrograph of Coarse Structure at D. ×200.

Fig. 6. Photomicrograph of Structure at C. ×200.

Fig. 7. Photomicrograph of Structure at F. ×200.

Fig. 8. Photomicrograph of Structure at F. ×1000.

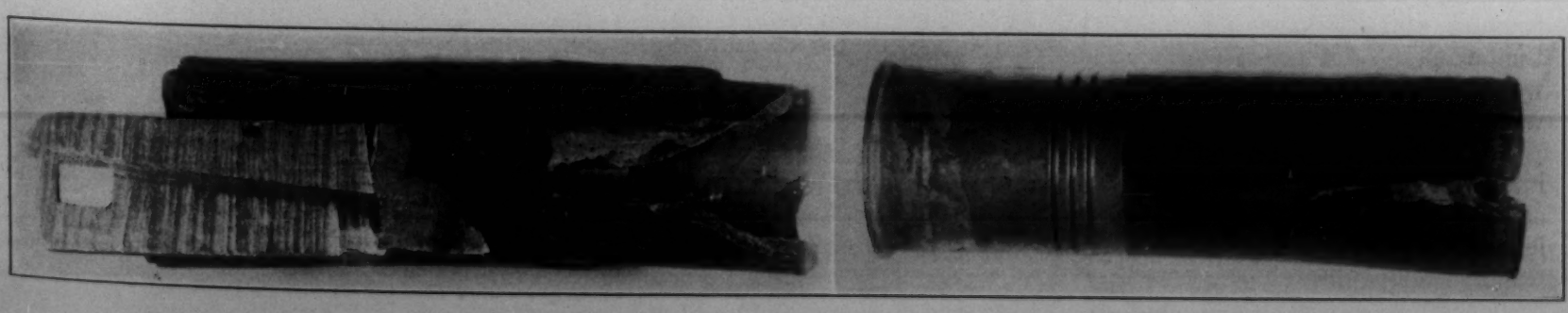


Fig. 9. Fracture on Inside of Barrel at E Which Probably Existed before the Explosion.

Fig. 10. Effect of Fracture at E on the Shell.

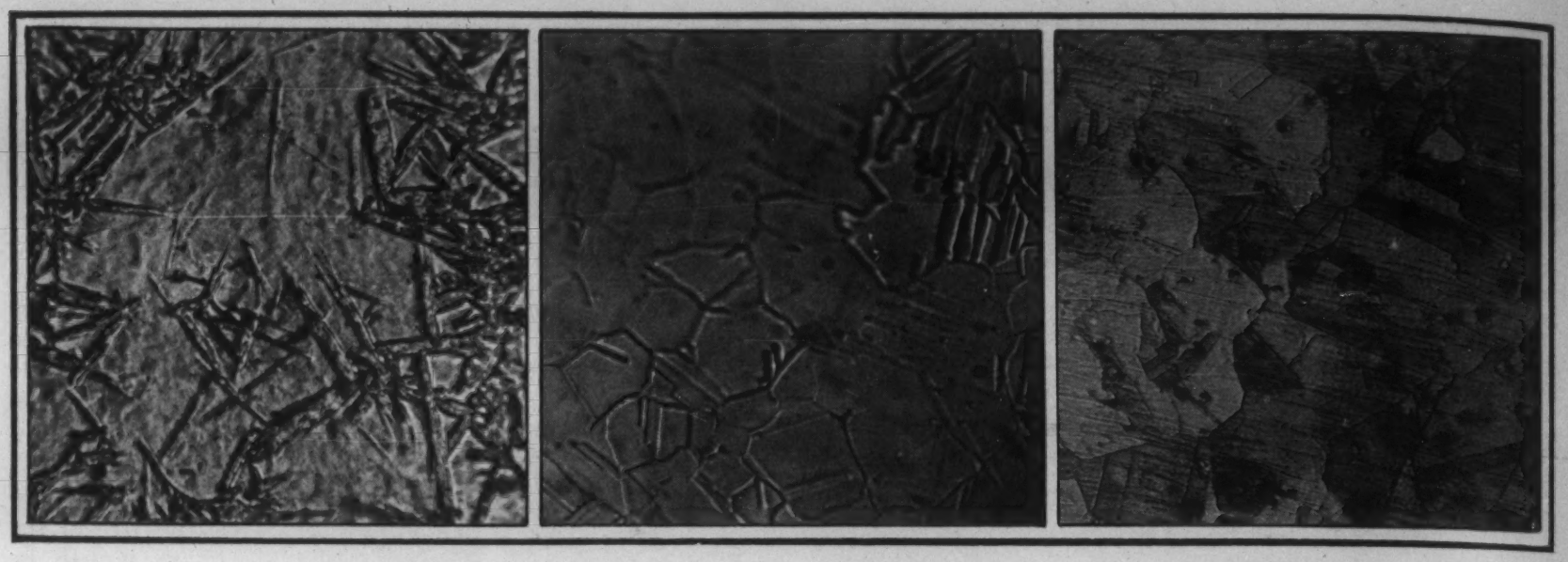


Fig. 11. Photomicrograph of Embedded Brass before Annealing. ×1000.

Fig. 12. Photomicrograph of Embedded Brass after Annealing. ×1000.

Fig. 13. Photomicrograph of Cartridge Brass. ×100.

which is known as a brass or a solid solution of zinc in copper. This opinion is substantiated by a photomicrograph of the brass on the shell which was found in the gun. This photomicrograph at 100 diameters is shown in Fig. 13.

The similarity of the two structures is obvious. It therefore seems quite conclusive that a shell of smaller gage was contained in the gun at a position about between the points C and D, and that the brass of the cartridge as it was thrown out came in contact with the barrel at point C and embedded some of its material in the steel.

This conclusion is strengthened by a comparison of the effect of the explosion on this gun and the effect produced in a gun which is known to have had the barrel closed by a small gage shell. Photographs of this second gun are shown in Fig. 14. It will be noted that the explosion occurred at almost the identical position on the barrel, but this time in the left barrel, and this time resulting in the loss of the hunter's whole hand. The side view of the barrel shows a small amount of the cartridge at position A. This is the evidence which gave conclusive proof in this case that there had been a shell in the barrel. There is found at this position a small amount of the paper and also of the brass. The difference in the character of the explosions is attributed to the weakened structure of the first gun on the inside of the barrel. Naturally if all parts of the barrel were of equal strength the fracture would be from the outside of the barrel and the inside of the barrel would be reinforced by the contact with the other barrel.

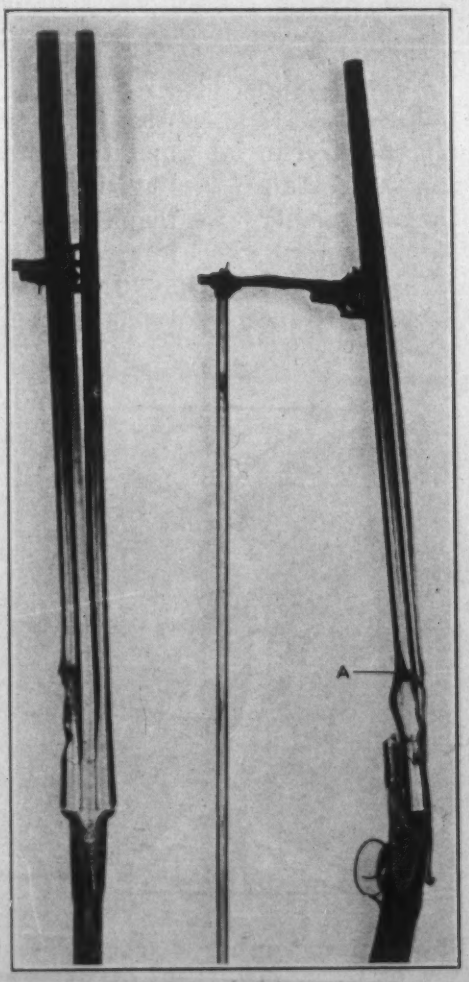


Fig. 14. Two Views of a Gun Which Is Known to Have Exploded because of Having the Barrel Closed by a Shell of No. 20 Gage.

The hunting party in which the first accident occurred had known of an earlier explosion of a shot gun due to the presence of a 20 gage shell in the barrel and took precautions not to have any 20 gage guns in the party, and so far as was known, no 20 gage shells. The gun had been carefully inspected so that the possibility of a shell having gotten into the gun while in storage during the summer months is rather remote. However, a brother of the man who used the gun in question owned a 20 gage gun. Some of his hunting clothes were in the party. This immediately suggests the possibility of a 20 gage shell having been left in the hunting clothes from the previous season and thus accidently getting into the gun. Naturally, the hunter who is watching his game while loading his gun might not give careful attention to each individual shell.

Another point of importance is that it is said that new boxes of shells have sometimes, though very rarely, been found in which shells of smaller gage were accidentally packed in with other shells. Quite definite reports have been heard that No. 16 gage shells have been found packed with No. 12's, and this immediately suggests the possibility of No. 20 gage shells getting into boxes of No. 12's. As hunters will understand, shells should fit the boxes tightly and in the presence of small gage shells can be detected very easily by the fact that they do not fill the box.

These two possibilities seem to be the most plausible explanations of the possibility of the small gage shell getting into the gun. They also suggest the necessary precaution of carefully examining all shells both in the original package and in the supply taken on the hunting trip. Furthermore, the possibility of having shells of different gage in hunting clothes is important and should be carefully guarded against.

It should be of some interest to the manufacturers of guns of this type to know that they should watch out against injuring the quality of their material in the brazing operation.

Mechanical and Creep Properties of Molybdenum Cast Iron

BY C. H. LORIG* AND F. B. DAHLE*

INCREASING utilization of molybdenum-containing cast iron for parts subjected to severe service conditions brings to the foreground a consideration of its mechanical properties.

It is unfortunate that the information found in the literature on molybdenum cast iron is based primarily on laboratory tests with scarcely a mention of its behavior in service. This is not unexpected, since the commercial use of this material began so recently that records of service have, as yet, not been compiled. A fairly accurate estimate of its properties and behavior, however, may be made from the somewhat incomplete data at hand.

Although there is evidence that an easily dissociated double carbide is formed when molybdenum is added to cast iron, it combines preferentially with ferrite to form a solid solution.[1] Its distribution between ferrite and carbide will tend not only to strengthen and toughen cast iron and increase its hardness, but also to alter the graphite and carbide distribution to some extent.

In cast iron containing carbon and silicon in amounts to bring them beyond the sensitive range of compositions bordering on white iron, the quantity of combined carbon is not appreciably affected by molybdenum additions up to 1%.

* Battelle Memorial Institute.

It is only when the compositions of the irons or the cooling rates are such as to bring them within or near the mottled cast iron range that there is a slight increase in the combined carbon with increased molybdenum content.

Investigations,[2,3,4,5,6,7] have shown that molybdenum causes the graphite to separate as globules or as small crumpled plates instead of the flat plates that usually occur in unalloyed gray cast iron. Microphotographs comparing the form of the graphite particles in the cast irons with and without molybdenum are shown in Figs. 1 and 2.

It is a common experience to find a well developed dendritic structure in molybdenum cast iron made in an electric furnace. The occurrence of the graphite in a dendritic pattern is believed to result when molybdenum cast iron is highly superheated. Structures such as those appearing in Figs. 3 and 4 are practically avoided if the metal is not heated beyond 1425° C. (2600° F.) before it is cast. In the heat treated specimen, Fig. 4, the graphite plates may have increased in size due to the decomposition of a portion of the carbide.

It has been reported by Swinden[8] that molybdenum decreases the amount of carbon in the eutectoid; consequently an entirely pearlitic matrix would be expected to occur with a lower combined carbon content in molybdenum iron than in an unalloyed iron.

Fig. 1. Molybdenum Free Gray Iron Containing 2.78% Total Carbon, 0.63% Combined Carbon, and 1.50% Silicon. Unetched. Mag. 100×.

Fig. 2. Gray Iron Containing 0.83% Molybdenum, 2.75% Total Carbon, 0.48% Combined Carbon, and 2.10% Silicon. Unetched. Mag. 100×.

Fig. 3. Gray Iron Containing 0.92% Molybdenum, 2.80% Total Carbon, 0.86% Combined Carbon, and 1.89% Silicon. Unetched. Mag. 100×.

Fig. 4. Same as Fig. 3, but Heat Treated at 1600° F., Furnace Cooled to 1400° F., and Then Air Cooled. Unetched. Mag. 100×.

Fig. 5. Cast Iron Containing 1.58% Molybdenum, 2.80% Total Carbon, 0.86% Combined Carbon, and 2.02% Silicon. Etched with 5% Picric Acid. Mag. 500×.

Fig. 6. Molybdenum-Free Cast Iron. Same as Fig. 1. Etched with Picric Acid. Mag. 500×.

Fig. 7. Molybdenum Cast Iron. Same as Fig. 2. Etched with Picric Acid. Mag. 500×.

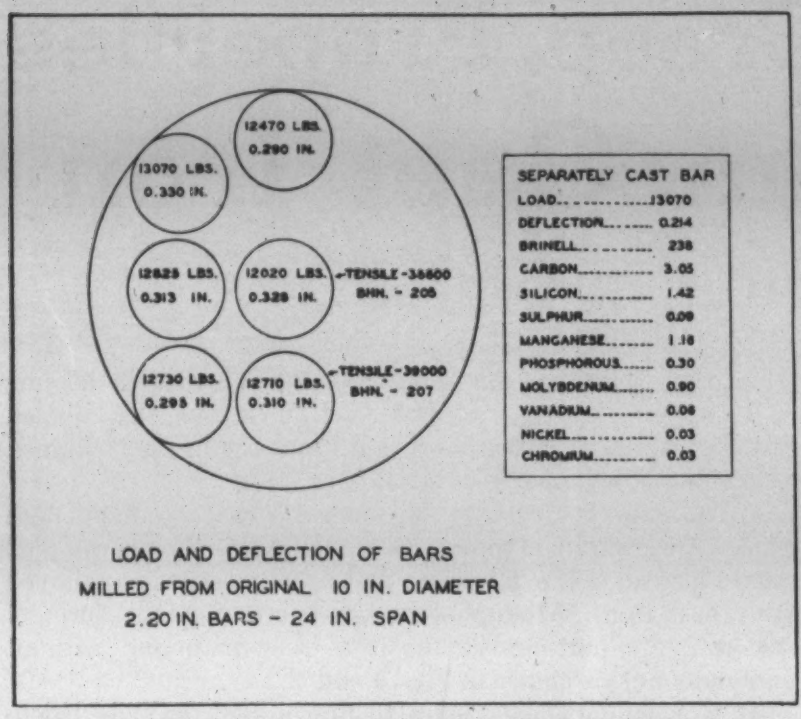


Fig. 8. Properties of Molybdenum Cast Iron as Influenced by Size of Section. Separately Cast Bar 2 In. in Diameter. MacKenzie. (The tensile tests were made with the United States Ordnance standard specimen for cast iron, the bars being machined to a diameter of 1.129 inches with a gage length of 1 inch.)

Besides lowering the carbon content at the eutectoid, the pearlitic matrix is emulsified and refined by molybdenum. Such structural refinements have been confirmed through a number of investigations. Smith and Aufderhaar[3] found that a fine pearlitic or "sorbito-pearlitic" structure in gray cast iron is induced by molybdenum. Musatti and Calbiani[5] observed that the pearlite in molybdenum irons is considerably finer than in unalloyed irons, and that not much change in structure occurred with less than 1.5 or 1.6% molybdenum. As the molybdenum is increased to 2.5% a troosto-martensitic or martensitic-sorbitic structure is formed. If the molybdenum content becomes excessively high, a peculiar, unidentified structure, often termed "pseudo-martensitic," is formed, which structurally has characteristics of a molybdenum-bearing carbon steel. A structure of this type is shown in Fig. 5. Both the carbon and molybdenum contents of the cast iron seem to determine the composition range wherein this structure appears. With the general refinement in structure of molybdenum cast iron, Challansonnet[9] observed small brilliant spots or particles, probably complex carbides, occuring in the sorbite. These spots could not be found in molybdenum cast iron containing nickel. The emulsification and refinement of the pearlite by molybdenum is shown in Figs. 6 and 7, where the microstructure of an unalloyed gray cast iron is compared with that of an iron very similar in composition, but containing 0.83% molybdenum. The molybdenum iron, Fig. 7, contains pearlite, ferrite and the unidentified structure which has been termed "pseudo-martensite."

Merten[10] has stated that the production of a high strength gray iron depends primarily upon preventing the precipitation of graphite in large flakes, and that such flakes are prevented by molybdenum. Not only are the properties of cast iron improved by molybdenum in this manner, but it also strongly annuls the effect of section size, a factor so important in the strength of gray cast iron. MacKenzie[11] presented the data given in Fig. 8 to compare the properties of bars machined from various locations in a 10 inch round molybdenum casting with the properties of bars of the same iron, cast as 2 inch rounds. It was pointed out that the separately cast bar (2 inch diameter) represented the transverse strength fairly well, even of the 10 inch diameter bar, but that the deflection is considerably lower and the Brinell hardness higher for the separately cast bar.

WITH so much of promise showing up on so short an acquaintance of foundrymen and engineers with molybdenum cast iron, it seems probable that if anywhere near as much effort were put on research in and development of these irons as has been put on nickel and nickel-chromium cast iron, the former would secure almost as definite a place in industry as have the latter. Molybdenum has firmly established itself as an alloying element for steel within the last few years, generally in conjunction with one or more other alloying elements, each element being called upon to provide certain specific properties in a balanced composition. It is not unlikely that a similar development will occur with cast iron.

The differences in the cast iron compositions, the melting and casting practices, and the methods of testing used in the various reported investigations to determine the effects of molybdenum on the mechanical properties of cast iron, require that a degree of caution be observed in comparing the results of one investigator with those of another.

Because it is difficult to compare in a broad way the effects of molybdenum on the mechanical properties of cast iron, each property is to be considered individually in the light of the data that now exists.

Brinell Hardness. The experiences of the investigators regarding the effects of molybdenum on the Brinell hardness of gray cast iron are not in complete accord. The experiments of Campion[12] on gray iron indicated that the addition of 1% molybdenum lowered the Brinell hardness. Smalley[1] reported no apparent effect on the Brinell hardness on adding 0.11% molybdenum to an iron containing 3.07% carbon, 2.17% silicon and 0.56% manganese. In a more extended investigation[2] he found that a slight increase in hardness occurred when 0.5% molybdenum was added to cast iron.

In contrast to the finding of Campion, the investigations of Piwowarsky,[13] Smith and Aufderhaar,[3] Musatti and Calbiani[5] Sherwin and Kiley,[14] Küster and Pfannenschmidt[15] show a gradual increase in Brinell hardness with the molybdenum content. In their investigations with test bars containing 3.32% total carbon, 0.65% combined carbon, 2.18% silicon, 0.65% manganese, 0.37% phosphorus, 0.060% sulphur and with increasing molybdenum content up to 3%, Smith and Aufderhaar found a general linear increase in Brinell hardness from a value of 207 for cast iron with no molybdenum to a value of 321 for iron containing 3% molybdenum. In a

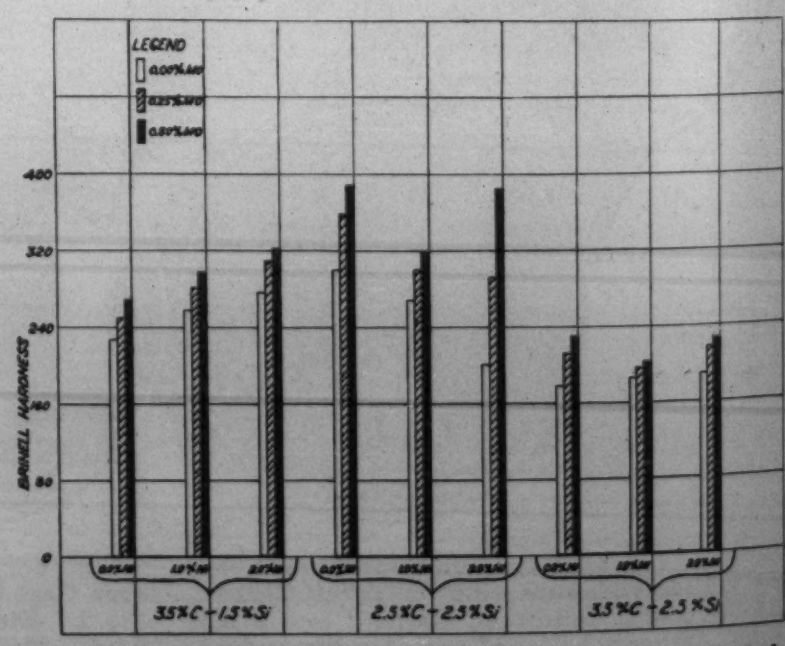


Fig. 9. Brinell Hardness of Three Series of Nickel-Molybdenum Cast Irons.

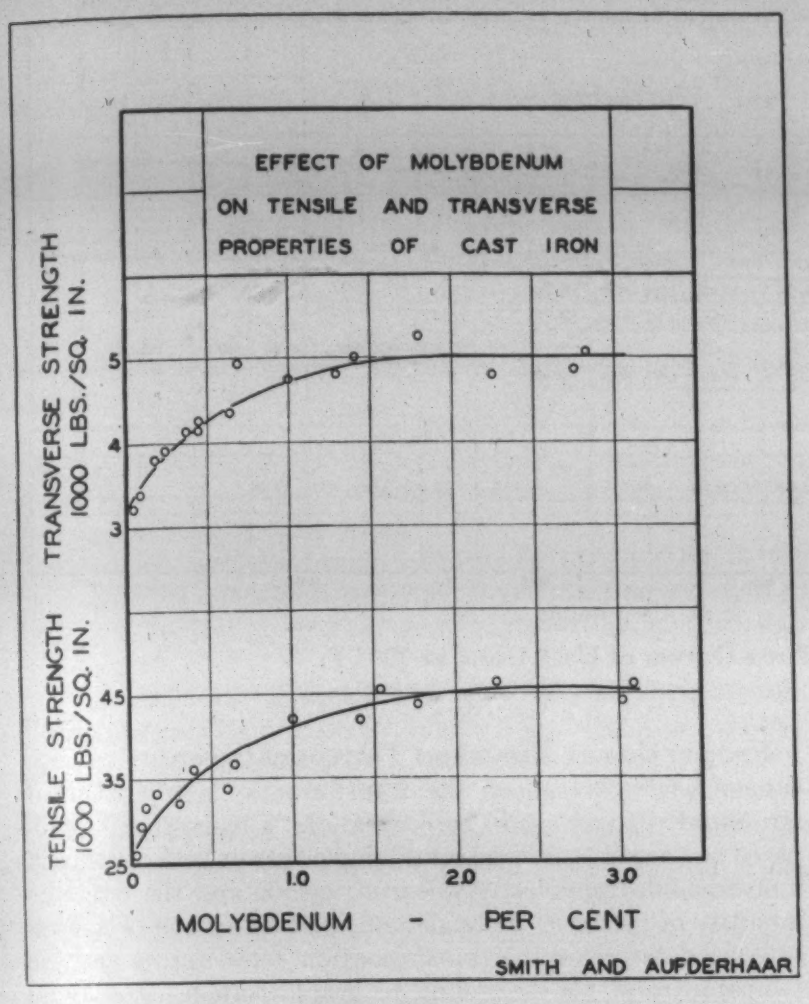


Fig. 10. **Effect of Molybdenum on the Properties of Gray Cast Iron.**

later article Smith and Aufderhaar[16] reported that in an iron containing 3.66% total carbon, 1.61% silicon, 0.62% manganese, the addition of 0.47% molybdenum increased the Brinell hardness from 179 to 207.

The combined effects of molybdenum and nickel on the Brinell hardness of 3 series of cast irons have recently been studied by Challansonnet.[9] Each series contained 0, 1 and 2% nickel with either 0.25 or 0.5% molybdenum. The hardness values are plotted in Fig. 9, and in all cases molybdenum caused a slight increase in hardness.

The investigations enumerated covered a wide range of cast iron compositions, and almost without exception a slight increase in Brinell hardness with the molybdenum content has been reported. The increase in Brinell hardness, irrespective of the chemical composition of the cast iron seems to be well established by all the latest investigations.

Tensile and Transverse Strengths. For the same cast iron for which he reported a decrease in Brinell hardness, Campion[12] found that the addition of 1% molybdenum increased the transverse strength of a 1 inch square bar, tested at a 12 inch span, from 2136 to 2730 lbs. The tensile strength for this iron increased from 30,200 lbs./in.^{2} to 39,400 lbs./in.^{2}

Smalley[2] reported the properties of a few molybdenum cast irons in the range of composition from 2.80 to 3.50% carbon and from 1.10 to 2.00% silicon. He concluded that 0.5% molybdenum produced an all-around improvement in the properties of cast iron.

Piwowarsky[13] arrived at the same conclusions from results on 3 series of high carbon cast irons containing, respectively 1, 1.75 and 2.75% silicon. Up to 0.5% molybdenum, the mechanical properties of the cast iron were improved, and no further improvement in properties resulted on increasing the molybdenum to 1%.

Piwowarsky selected for his tests a cast iron of such high carbon content (3.4 to 4.0% carbon) that the conclusions are of interest more from an experimental rather than from a commercial point of view.

Other investigators dealt with cast irons of lower carbon contents. Smith and Aufderhaar,[3] and Musatti and Calbiani[5] made tensile tests to show the effects of molybdenum on low and medium carbon cast iron. Smith and Aufderhaar assumed that, in their tests, except for the molybdenum which varied up to 3%, the analysis of the bars to be 3.32% carbon, 0.65% combined carbon, 2.18% silicon, 0.52% manganese, 0.37% phosphorus and 0.060% sulphur.† The results of their study are plotted in Fig. 10.

The investigations of Musatti and Calbiani cover a wider range of compositions. Their values on the modulus of rupture and the tensile strengths of various classes of cast irons are plotted in Fig. 11. As in the case of the curves in Fig. 10, maxima appear at a molybdenum content of 1.5 to 2.0%.

Sherwin and Kiley[14] reported an increase in the transverse strength from about 2000 to about 2850 lbs. (bars 1.20 inch diameter with 18 inch span) and an increase in the tensile strength from 30,300 to 47,200 lbs./in.^{2} on adding 0.82% molybdenum to a cast iron with an approximate composition of 3.45% carbon, 1.85% silicon and 0.80% manganese.

Küster and Pfannenschmidt[15] found but slight variation in the transverse and tensile strengths on increasing the molybdenum content of a cast iron from 0.80 to 2.23%. These samples of cast iron had an average carbon and silicon content of 3.40 and 2.48%, respectively. They recorded changes in the tensile strength from 41,000 to 49,000 lbs./in.^{2} on increasing the molybdenum content from 2.23 to 2.50%.

† J. T. MacKenzie in a private communication stated that the sum of the carbon plus one-third of the silicon in samples used by Smith and Aufderhaar actually varied from 3.72 to 4.14%. Chemical analyses were made of some of the bars by The American Cast Iron Pipe Company.

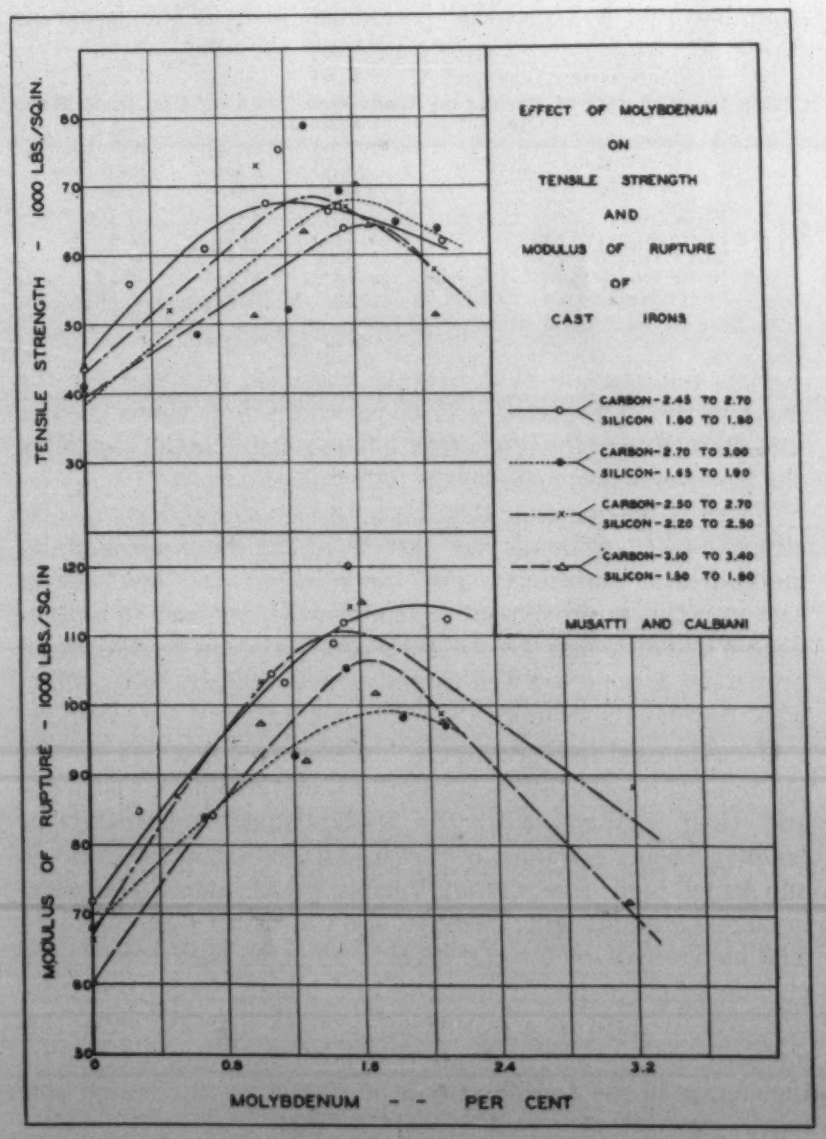


Fig. 11. **The Modulus of Rupture and Tensile Strength of Various Classes of Molybdenum Cast Iron.**

The corresponding values for the modulus of rupture of the same iron cast in bars, whose dimensions were not given, were 70,700 and 84,400 lbs./in.^{2} The marked increase in mechanical properties at the high concentrations of molybdenum are unusual in the light of the work of Smith and Aufderhaar and Musatti and Calbiani reviewed above.

An extensive summary of the mechanical properties of a variety of molybdenum cast irons has been published by the Climax Molybdenum Company.[6] Transverse strengths on 1.20 inch diameter bars supported on 12 inch centers of 4000 to 5600 lbs. and tensile strengths of 34,600 to 38,900 lbs./in.^{2} are given for molybdenum automotive cast irons for cylinder blocks and pistons. The analyses of these irons are in the range of 3.20 to 3.44% carbon, 1.90 to 2.42% silicon, 0.44 to 0.90% manganese, and 0.30 to 0.40% molybdenum. Die irons with 0.94 to 1.60% molybdenum and slightly lower in carbon and silicon have transverse strengths of 5500 to 6700 lbs. The tensile strength of a high test iron with 2.5% carbon, 2.25% silicon, and 0.50% molybdenum is given as 63,000 lbs./in.^{2} Its transverse strength, determined for a 1.20 inch diameter specimen over a span of 12 inches was 7750 lbs.

A report by Bromer[17] on tests of 4 grades of iron made at a foundry over a 2 months' period is given in the following table.

Table 1.—Summary of Results on Transverse Tests * of Cast Irons Made Over a Period of 2 Months

Iron	Number Bars Tested	Average Load lbs.	Average Deflection Inches
Plain Iron	88	4738	0.128
Plain Iron (18" Span)	14	2722	0.24
Ni-Cr Iron (Low)	32	4740	0.137
Ni-Cr Iron (High)	42	4738	0.13
Molybdenum Iron	41	5400	0.157

* 1.20 inch diameter specimens—12 inch span unless noted.

It is unfortunate that average chemical analyses for the irons were not reported. Without these data there is some uncertainty as to the interpretation one should make regarding the transverse properties of the molybdenum iron.

There is no question that both the tensile and transverse strengths of an unalloyed cast iron can be improved by molybdenum additions. For the medium and low carbon cast iron this improvement continues with increase in molybdenum and although the optimum concentration for maximum properties is none too well established, it appears to be somewhat beyond 1% or more.

Compressive Strength. A few investigators have determined the compressive strengths of molybdenum cast irons and their changes with the molybdenum concentration. Smalley,[2] using cylinders of cast iron 0.798 inches in diameter and 1 inch high; Piwowarsky,[13] using a specimen 0.71 inches in diameter and height; Musatti and Calbiani,[5] with cylinders 0.63 inches in diameter and height; and Challansonnet,[9] with cylinders 0.35 inches in diameter and height, found the compressive strength of a given cast iron to increase with the molybdenum content at a rate that is directly proportional to the change in the tensile strength. Thus by increasing the tensile strength of a cast iron 10% with a given quantity of molybdenum, there is a corresponding percentage increase in the compressive strength of the iron.

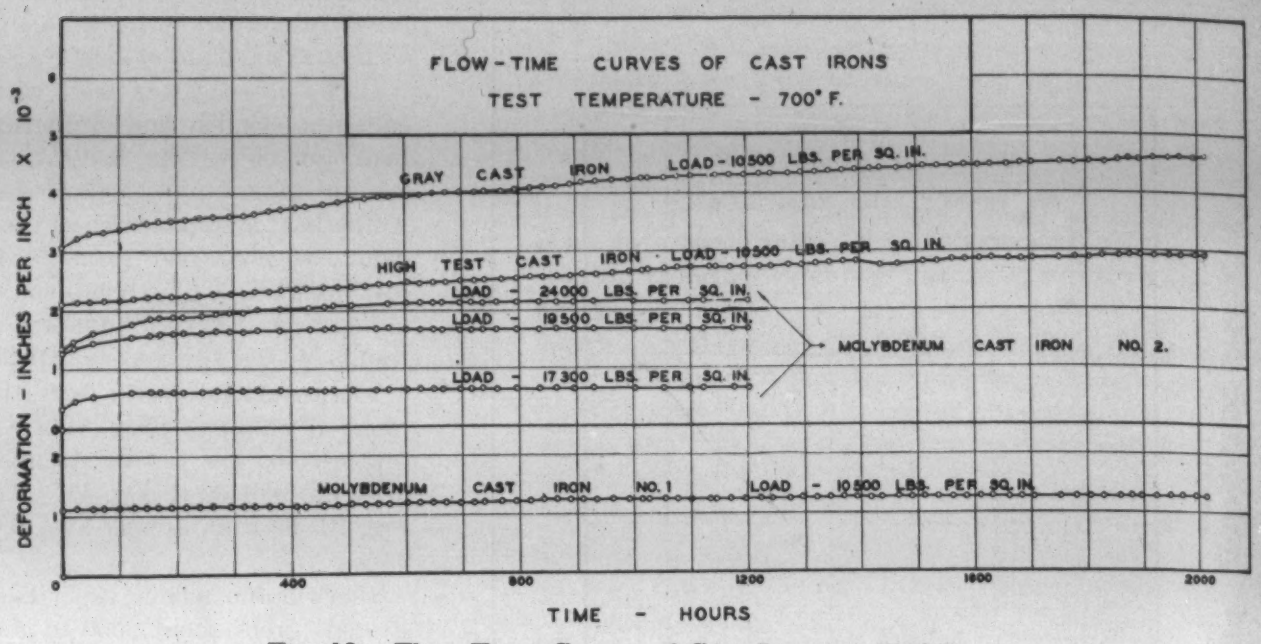

FLOW - TIME CURVES OF CAST IRONS
TEST TEMPERATURE - 700° F.
GRAY CAST IRON LOAD - 10500 LBS. PER SQ. IN.
HIGH TEST CAST IRON LOAD - 10500 LBS. PER SQ. IN.
LOAD - 24000 LBS. PER SQ. IN.
LOAD - 19500 LBS. PER SQ. IN.
LOAD - 17300 LBS. PER SQ. IN.
MOLYBDENUM CAST IRON NO. 2.
MOLYBDENUM CAST IRON NO. 1 LOAD - 10500 LBS. PER SQ. IN.
DEFORMATION - INCHES PER INCH X 10⁻³
TIME - HOURS
0
400
800
1200
1600
2000

Fig. 12. Flow-Time Curves of Cast Irons at 700° F.

Properties at Elevated Temperatures. Cast iron cannot be heated above the transformation temperature if structural changes are to be prevented. Challansonnet[9] prepared a series of cast irons containing either or both nickel and molybdenum from electrolytic iron, carbon and the requisite quantity of nickel or molybdenum, and by means of a dilatometer determined the transformation temperature and the temperature of the beginning of graphitization. He found that molybdenum raised the temperature of graphitization so that the irons containing more than 0.25% molybdenum with no nickel showed no graphitization up to 1100° C. in the dilatometric tests, and 0.50% molybdenum was sufficient to prevent graphitization up to this temperature in an alloy containing 1.0% nickel. The rates of heating and cooling of the specimens in the dilatometric determinations were 250° and 300° C. per hour, respectively. The transformation temperatures of cast iron containing increasing percentages of molybdenum that are given in the table are taken from the results of this investigation.

Table 2.—Transformation Temperatures of Cast Iron Containing Molybdenum

Total Carbon %	Mo %	Si %	Mn %	Transformation Temperatures Ac ° C.	Ar ° C.	Difference Ac-Ar ° C.
3.72	Nil	Nil	Nil	700	630	70
3.62	0.26	Nil	Nil	725	625	100
3.74	0.50	Nil	Nil	725	575	150
3.65	0.26	2.6	0.5	800	650	150
3.67	0.50	2.6	0.5	800	500	300

In common with steel, the presence of molybdenum increases the difference between the transformation temperature observed on heating and that observed on cooling.

The growth of cast iron on repeated heating to high temperatures is undoubtedly affected by its molybdenum content. The retarding influence of molybdenum on the decomposition of cementite and its comparatively mild tendency to form a double carbide are factors which make for slower rates of growth.

Musatti and Calbiani[5] determined the increase in volume of several small cylinders of cast iron 0.78 inch in diameter and 3.93 inches in length on heating at 800° C. (1470° F.) for 24 hours. Their results were given as follows:

No. 1 (No Mo)	8.0% increase
No. 2 (No Mo)	7.8% increase
No. 8 (0.74% Mo)	6.1% increase
No. 10 (1.08% Mo)	5.8% increase
No. 18 (1.54% Mo)	1.75% increase

On heating for 100 hours at 800° C. (1470° F.) all 5 of these irons increased in volume approximately 30%. There is an apparent decrease in the rate of growth with increased molybdenum content, but this advantage is completely masked on continued heating.

Claims[6] are made that molybdenum cast irons are resistant to growth, and to substantiate this statement the dilation charts for plain carbon iron, nickel cast iron, and molybdenum cast iron are compared. After the first heating to 873° C. (1600° F.), no growth could be detected in the molybdenum cast iron. This comparison included data on the growth of cast iron resulting from the decomposition of cementite, and does not include the growth from oxidation of the graphite and matrix. Since the molybdenum irons are not resistant in the sense of being non-scaling under oxidizing conditions at elevated temperatures, it is improbable that such dilation studies are an index of the total growth-resistant properties of a material.

Andrew and Hyman[18] found that 0.58% molybdenum in an iron containing 3.33% total carbon, 0.32% combined carbon and 1.31% silicon had no detectable effect on the growth or increase in volume on heating.

Seemingly, growth occurs less rapidly at the start in the molybdenum-containing iron but as yet there are no data to support the belief that long-time growth is in any way diminished.

The tensile strengths at 425° C. (800° F.) of 3 molybdenum cast irons were determined at the Battelle Memorial Institute for the Worthington Pump and Machinery Corporation, through whose courtesy the data are made available here. They are listed in the following table, together with the mechanical properties of the irons at room temperature.

700° F., and far better resistance to creep than the gray and high test cast irons.

With reference to Fig. 12, iron No. 2 loaded at 17,300 lbs./in.² shows better resistance to creep than iron No. 1 loaded at 10,500 lbs./in.². It should also be noted that all 3 samples of iron No. 2 show constancy of dimensions in a length of time equally as short or shorter than iron No. 1.

The tensile strengths of the molybdenum cast iron test bars after completing the creep tests were determined as 50,750 lbs./in.² for iron No. 1 and 52,100 lbs./in.² for iron No. 2. A small flaw in the fracture of iron No. 1 accounted for its drop in tensile strength.

As evidence of the low creep resistance of ordinary gray cast iron, the results of Honegger[19] on long duration tensile tests are given. Heating the cast iron to about 750° F. and applying a load of 12,500 lbs./in.² the following results were obtained:

Table 6.—Load Duration Tensile Test on Cast Iron

Lot *	Tensile Strength, Cold, lbs./in.²	Bending, Cold ** lbs./in.²	Deflection ** Inches	Creep in 24 Hours ***	Rate of Flow 25th to 145th Hour
1	29,100	60,000	0.51	1.1%	0.0017% per hr.
2	22,300	45,500	0.49	0.9% broke	.....
3	30,500	55,500	0.47	0.8%	0.004% per hr.

* The composition of the irons is not given.
** Dimension of bar and span not stated.
*** Exclusive of thermal expansion, includes unmeasured stretch of test bar ends.

Table 3.—Mechanical Properties of Molybdenum Cast Iron at Room and Elevated Temperatures

No.	Total C %	Graphitic C %	Combined C %	Si %	Mn %	P %	S %	Mo %	Transverse Test* Load lbs./in.²	Transverse Test* Deflection In.	Tensile Strength lbs./in.² Room Temp.	Tensile Strength lbs./in.² 425° C. (800° F.)	Brinell Hardness
1	3.40	2.70	0.70	1.50	0.75	0.15	0.08	..	3900	0.16	32,900	31,400	197
2	2.75	2.38	0.37	2.42	0.68	0.06	0.07	0.63	4785	0.17	43,000	39,900	192
3	2.75	2.27	0.48	2.10	0.70	0.06	0.06	0.83	6300	0.17	59,500	52,900	241
4	2.80	2.40	0.40	2.02	0.65	0.06	0.05	1.58	6565	0.18	59,800	55,100	223

Table 4.—Mechanical Properties of Molybdenum Cast Iron

Type of Iron	Total C %	Graphitic C %	Combined C %	Si %	Mn %	P %	S %	Mo %	Transverse Test* Load lbs./in.²	Transverse Test* Deflection In.	Tensile Strength lbs./in.²	Brinell Hardness
Gray	3.40	2.70	0.70	1.50	0.75	0.15	0.08	..	3900	0.16	32,900	197
High Test	2.95	2.10	0.85	2.45	0.75	0.05	0.10	..	4500	0.14	45,000	237
Mo. No. 1	2.75	2.27	0.48	2.10	0.70	0.058	0.62	0.83	6300	0.17	59,500	241
Mo. No. 2	2.72	2.06	0.66	2.50	0.66	0.054	0.71	0.83	5800	0.145	52,500	241

* 1.20 inch diameter specimen—12 inch span.

Table 5.—Deformation of Cast Iron at 700° C. under Load

Type of Iron	Load lbs./in.²	Inches per Inch per Hour First 150 Hours	150–450 Hours	450–900 Hours	900–1200 Hours	1200–2000 Hours
Gray	10,500	12.1×10^{-7}	12.1×10^{-7}	5.9×10^{-7}	3.4×10^{-7}	3.0×10^{-7}
High Test	10,500	5.3×10^{-7}	5.3×10^{-7}	5.3×10^{-7}	3.4×10^{-7}	0*
Mo. No. 1	10,500	0.8×10^{-7}	0.8×10^{-7}	2.2×10^{-7}	0	0
Mo. No. 2	17,300	10.0×10^{-7}	0	0	0	0
Mo. No. 2	19,500	16.7×10^{-7}	3.7×10^{-7}	0	0	0
Mo. No. 2	24,000	30.0×10^{-7}	6.7×10^{-7}	1.6×10^{-7}	0	0

* 0 from 1850 to 2000 hours.

All these irons maintain their original strength pretty well on short-time test at 800° F., with the strong molybdenum irons showing up attractively for high temperature service.

The striking difference in favor of the molybdenum iron is, however, more clearly brought out in "creep" or "time-flow" curves.

An interesting comparison was made of the time-flow characteristics of an ordinary gray cast iron, a high test cast iron, and 2 lots of molybdenum-containing cast iron at Battelle Memorial Institute. The tests at 10,500 lbs./in.² load were made for the Worthington Pump and Machinery Corporation. The mechanical properties and chemical composition of the samples are given in Table 4, while the summary of the tests are included in the curves of Fig. 12 and the data of Table 5.

It may be seen that the creep rate for molybdenum cast iron No. 1 is decidedly less than that for the gray and the high-test cast irons tested at the same load and temperature. In fact, after the first 900 hours little or no deformation was detected for molybdenum cast iron No. 1, while the other 2 irons were still elongating appreciably, although at a decreasing rate.

The results obtained indicated that molybdenum cast iron No. 2, although inferior in physical properties to No. 1, has equal or better resistance to creep than No. 1 when tested at

Both unbroken specimens were still flowing at the end of the test. At the same load but at about 830° F., iron No. 1 crept 1.5% and broke. If it be assumed that any bar of the iron would break at the same extension, the bar stressed at 750° F. would also have broken in another 120 hours, since the curve showed no cessation of creep at the time the test was stopped. Iron No. 3, though not stretched as far as No. 1 at the end of the test, was creeping at a faster rate than No. 1, and its rate showed no signs of diminution. In another 120 hours, at the rate it was extending, it would also have stretched 1.5%.

The results on the creep of cast iron, taken as a whole, point to the good properties of the molybdenum cast iron at elevated temperatures. The molybdenum irons tested at the Battelle Memorial Institute gave creep limits that are considerably higher than those of the unalloyed cast irons. As a matter of

fact, the values on creep and the resistance of molybdenum cast iron to flow under load at high temperatures appear to be commensurable with those obtained on some steels.

While the creep data on molybdenum cast iron here presented are not sufficient to allow full comparison of its high temperature behavior with that of other alloys of engineering interest (since it will clearly stand higher temperature or higher loads than those at which it has so far been tested), it seems that for some types of service at moderately elevated temperatures, it deserves consideration.

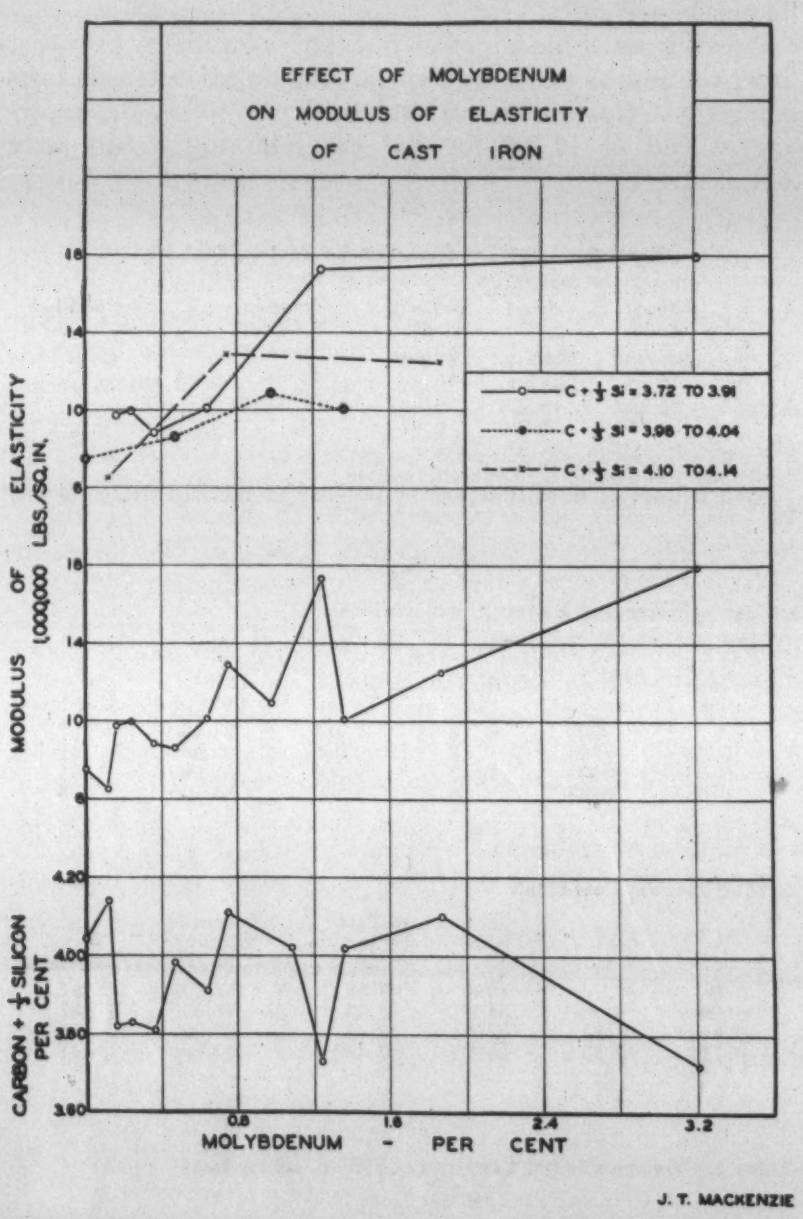

EFFECT OF MOLYBDENUM
ON MODULUS OF ELASTICITY
OF CAST IRON
MODULUS OF ELASTICITY (000,000 LBS./SQ.IN.
CARBON + ¼ SILICON PER CENT
MOLYBDENUM - PER CENT
C + ¼ Si = 3.72 TO 3.91
C + ¼ Si = 3.98 TO 4.04
C + ¼ Si = 4.10 TO 4.14
J. T. MACKENZIE

Fig. 13. Modulus of Elasticity of Small Specimens of Molybdenum Cast Iron.

Other Properties of Molybdenum Cast Iron. A useful property of cast iron is its rigidity, and this property is related to the modulus of elasticity and the deflection under transverse load.

The effect of molybdenum on the modulus of elasticity was determined by MacKenzie[20] on small specimens of cast iron used by Smith and Aufderhaar.[3] Broken transverse bars from Smith and Aufderhaar were analyzed and machined into small bars with a 1/2 inch diameter section. The results of transverse tests made on the small bars with a 5 inch span are plotted in Fig. 13. A general increase in the modulus of elasticity occurs with the molybdenum content of the cast iron, though in this case the carbon and silicon contents, expressed in terms of the sum of the carbon plus one-third of the silicon have in themselves an appreciable effect upon the rigidity of cast iron.

On the whole, the deflections of transverse test bars at the time of rupture are slightly greater for the irons of low and medium molybdenum content than for the unalloyed cast irons of approximately the same chemical compositions. Although this increase in deflection with moderate additions of molybdenum is appreciable the magnitude of the increase does not equal the accompanying increase in the transverse strength or the tensile strength of the iron. When the molybdenum exceeds 1 1/2 or 2%, the deflection of transverse bars at the time of rupture is frequently less than it is for the molybdenum-free iron of the same composition. The stiffening or increased rigidity of cast iron with molybdenum additions as manifested by transverse tests are illustrated by the results of Smalley[2] on mechanical properties of molybdenum cast iron.

Table 7.—Transverse Properties of Molybdenum Cast Iron. (Smalley)

No.	Total C %	Combined C %	Si %	Mn %	P %	S %	Mo %	Transverse Tests 1 × 2 in. Bar-12 in. Span Load lbs.	Deflection inch
1A	3.32	0.41	1.94	0.62	0.93	0.076	Nil	2812	0.12
1B	3.47	0.37	2.03	0.64	0.92	0.070	0.15	3010	0.12
1C	3.47	0.46	2.05	0.62	0.90	0.067	0.26	3240	0.13
1D	3.25	0.43	1.92	0.75	0.89	0.047	0.52	3940	0.15
2A	3.42	0.87	1.10	0.85	0.51	0.114	Nil	3940	0.12
2B	3.30	0.89	1.24	0.69	0.51	0.115	0.12	3970	0.13
2C	3.30	0.91	1.26	0.66	0.52	0.096	0.24	3950	0.13
3A	2.84	0.61	1.54	0.55	0.54	0.114	Nil	2972	0.12
3B	2.78	0.60	1.68	0.66	0.62	0.082	1.55	3233	0.10
4A	3.30	0.43	1.98	0.61	0.87	0.083	Nil	2762	0.12
4B	3.26	0.38	2.00	0.60	0.87	0.076	1.49	3122	0.116

In this investigation smaller deflections for greater transverse loads were reported for specimens containing 1.55 and 1.49% molybdenum, specimens 3B and 4B, Table 7, than for the same irons containing no molybdenum.

Drill tests by Smith and Aufderhaar,[3] Sherwin and Kiley[14] and tests conducted at Battelle Memorial Institute* have shown a decrease in machinability with the molybdenum content of cast iron. Smith and Aufderhaar observed that the machinability does not become notably difficult until the molybdenum had reached 1.5%. With 3% molybdenum, drilling was difficult, while a bar containing 4.40% molybdenum could not be drilled. The increased time of machining as evidenced by the drill test is said to be due to increased density or toughness of the iron and not to structures that would ruin a tool. In the Battelle tests a 1/4" high speed drill under a load of 69 lbs., drilling for 2 minutes gave the results shown in Table 8.

Table 8.—Machinability of Cast Irons

Type of Iron	PROPERTIES Brinell	Tensile Strength lbs./in.²	Depth Drilled inches
Gray	197	33,000	1.22
High Test	237	43,000	0.82
Molybdenum	241	59,000	0.89
1.5% Nickel	230	44,000	0.91

Thus, among strong irons the molybdenum iron is not inferior in machinability, though it is, of course, more difficult to machine than ordinary gray iron.

Smalley[2] observed no great effect on the machining properties of cast iron with 0.5% molybdenum, but found that a larger quantity rendered machining difficult. It is probable that the increased difficulty of machining is associated, in part, with the increase in hardness and strength of molybdenum cast iron.

Smalley,[2] Smith,[3] and Musatti and Calbiani[5] report that molybdenum in cast iron increases its resistance to wear. The latter investigators conducted extensive Amsler wear resistance tests on molybdenum cast iron and found that best results were obtained with 1.5 % molybdenum.

The successful commercial use of molybdenum cast iron for brake drums of powerful automobiles may be taken as practical evidence of good wear-resistance and good high-temperature properties.

Both Smith[4] and the Climax Molybdenum Company[6] maintain that molybdenum cast iron withstands atmospheric corrosion better than ordinary cast iron. According to the latter, a molybdenum content of 0.35% increases the resistance of cast iron to atmospheric corrosion and rusting appreciably.

* Tests for Worthington Pump and Machinery Corporation, through whose courtesy this statement is made.

The effects of molybdenum on the corrosion of cast iron in tenth normal solutions of sulphuric acid, nitric acid, hydrochloric acid, acetic acid, and in sodium hydroxide, potassium hydroxide, sea water, distilled water, and air were studied by Musatti and Calbiani.[5] They observed no beneficial effects on molybdenum but gave no data to substantiate their conclusions.

A study of the solubility of a gray iron containing no molybdenum and on one containing 0.83% molybdenum, when immersed in chemical solutions (the tests having no bearing on any other conditions than those existing in the particular solution), was made at the Battelle Memorial Institute for the Worthington Pump and Machinery Corporation. The loss of weight for both irons was practically the same in a 5% solution of sulphuric acid and in a 3% solution of sodium chloride.

Comprehensive corrosion data on molybdenum cast iron are not available; consequently its reaction to corrosive media are none too well known.

The increased strength and hardness of molybdenum cast iron, the superiority of its properties at elevated temperatures over those of ordinary cast iron, and its unusual resistance to creep and wear make the molybdenum cast iron particularly adaptable where severe service conditions are met.

The authors are indebted to H. C. Cross for data on creep tests, to J. T. MacKenzie for original data, to J. L. Gregg and G. T. Motok for the compilation of much of the data in the literature, and to R. J. Allen of the Worthington Pump and Machinery Corporation for permission to incorporate some of the data obtained at Battelle Memorial Institute in work for that firm.

Bibliography

[1] O. Smalley. The Effect of Special Elements on Cast Iron. *Foundry Trade Journal*, Vol. 26, 1922, pages 519–522.
[2] O. Smalley. Special Cast Iron. *Metal Industry*, London, Iron Foundry Section, Vol. 22, 1923, pages 35–38, 59–61, 82–85. The same Part II only, *Foundry Trade Journal*, Vol. 27, 1923, pages 3–5.
[3] E. K. Smith & H. C. Aufderhaar. Molybdenum in Cast Iron. *Iron Age*, Vol. 124, 1929, pages 1507–1509.
[4] J. Kent Smith. Molybdenum Improves Gray Iron. *Foundry*, Vol. 58, June 15, 1930, pages 54–55.
[5] I. Musatti & G. Calbiani. Le Ghise Speciali con particolare riguardo a Quelle al Molibdeno. *La Metallurgia Italiana*, Vol. 8, 1930, pages 649–669. The same, abstract translation, *Iron and Steel of Canada*, Vol. 13, 1930, page 222.
[6] Climax Molybdenum Company. Molybdenum in Cast Iron. Booklet 1931, 22 pages.
[7] Battelle Memorial Institute.
[8] Thomas Swinden. Carbon Molybdenum Steels. *Iron and Steel Institute, Carnegie Scholarship Memoirs*, Vol. 3, 1911, pages 66–124.
[9] Jean Challansonnet. Étude sur les fontes au Nickel-Vanadium et au Nickel-Molybdène. *Revue de Métallurgie*, Vol. 27, 1930, pages 573–603, 654–671.
[10] William J. Merten. Special Quality Gray Iron Castings. *Fuels & Furnaces*, Vol. 9, 1931, pages 195–198.
[11] J. T. MacKenzie. Discussion of a paper by J. W. Bolton & Hyman Bornstein. Effect of Elevated Temperatures on Certain Mechanical Properties of Gray Cast Iron and Malleable Iron. *Symposium on Effect of Temperature on the Properties of Metals, American Society for Testing Materials*, 1931, pages 299–321.
[12] A. Campion. Influence of Some Special Constituents on Cast Iron *Foundry Trade Journal*, Vol. 20, 1918, pages 467–470.
[13] E. Piwowarsky. Die Gusseisenveredelung durch Legierungs-Zusätze. *Stahl und Eisen*. Vol. 45, 1925, pages 289–297. The same translated, *Foundry Trade Journal*, Vol. 31, 1925, pages 331–334, 345–346.
[14] L. M. Sherwin & T. F. Kiley. Cupola High-Test and Alloy Irons in a Machine Tool and Gray Iron Jobbing Foundry. *Transaction and Bulletin, American Foundrymen's Association*, Vol. 2, 1931, pages 115–160.
[15] J. H. Küster & C. Pfannenschmidt. Ein Beitrag zur Frage des Einflusses von Molybdän und Titan auf die Eigenschaften von Grauguss. *Giesserei*, Vol. 18, 1931, pages 53–58.
[16] E. K. Smith & H. C. Aufderhaar. Tests Show Effect of Using Alloy Scrap in Making Pig Iron. *Iron Age*, Vol. 125, 1930, pages 156–158.
[17] H. E. Bromer. Electric Process Iron for Cylinder and Cylinder-Head Castings. *American Foundrymen's Association, Preprint* No. 31-13, 1931, 15 pages.
[18] J. H. Andrew & H. Hyman. High-Temperature Growth of Special Cast Irons. *Journal of the Iron and Steel Institute*, Vol. 109, 1924, pages 451–463.
[19] E. Honegger. Long Duration Tensile Tests on Metals at High Temperatures. *Brown Boveri Review*, Vol. 15, Nov. 1928, pages 315–320.
[20] J. T. MacKenzie. Private Communication.

◆ ◆ ◆ ◆ ◆

A. S. T. M. Committee on Electrical Alloys Outlines Work Ahead

Committee B-4 of the American Society for Testing Materials through the Chairman, Dean Harvey, Materials Engineer, Westinghouse Electric & Manufacturing Co., has outlined its work for the ensuing year. This committee functions in the field of electrical-heating, electrical-resistance and electric-furnace alloys.

Life Tests. The Subcommittee on Life Tests has made notable progress in the comparative tests to show the relation between the life of electrical heating wires as indicated by the A. S. T. M. Accelerated Life Test for Metallic Materials for Electrical Heating and the life of the same wire under service conditions in an electric toaster. Two lots of wire, short and long life, are being used and tests are made both on commercial circuits and circuits on which the voltage is closely controlled. Six laboratories are coöperating in the tests. The question of preparing an accelerated life test to allow larger sizes of wire to be tested is being studied.

Electrical Tests. A new Tentative Method of Test for Determining the Temperature-Resistance Constants of Resistance Alloys was approved for publication, at the recent annual meeting of the Society. It is expected this will be followed in commercial use. In order to facilitate this test, a method for making the resistance measurements within the accuracy called for in the test will be prepared.

Mechanical Tests. Several laboratories are trying the bend test for determining the elastic properties of alloys at temperatures up to 1000° C. The permanent change in curvature produced by heating metal strips to various temperatures while constrained to known curvatures has been determined. It has been shown that the proportional limit as determined by the tension test at room temperature corresponds to the sharp bend in the permanent bending curve at the same temperature.

The development of this test has been under the direction of Howard Scott, Research Engineer, Westinghouse Electric and is described in a paper "High Temperature Characteristics of Metals Revealed by Bending," which was presented at the 1931 annual meeting of the A. S. T. M. in Chicago.

Wrought and Cast Alloys for High-Temperature Use. The subcommittee in charge of this project is outlining a procedure for preparing cast test specimens for the tension test. This involves a study of mold construction and foundry practice necessary to insure a sound specimen.

A test specimen to determine the tendency to warp at high temperatures is under consideration and methods of tests for thermal conductivity and coefficient of linear expansion are being prepared.

Specifications for Heater Wires. The tentative specifications for 80–20 nickel-chromium and 60–15–25 nickel-chromium-iron alloys for electrical heating elements which have just been put out as tentative standards, will be followed in commercial use during the year. These specifications cover two grades of alloys which are in general use for electrical heating elements.

◆ ◆ ◆

Third International Conference on Bituminous Coal

A tentative list of speakers and subjects for the Third International Conference on Bituminous Coal to be held at the Carnegie Institute of Technology, Pittsburgh, November 16 to 21, has been announced by Dr. Thomas S. Baker.

Seventeen countries will be represented in the conference, and an attendance of well over 2000 persons is expected. The desperate plight of the coal industry has added impetus to the meeting, and the organizers feel that the conference comes at an appropriate time.

◆ ◆ ◆

The following members of the research staff of The Roessler & Hasslacher Chemical Company, Inc., have been transferred from the plant at Perth Amboy, N. J., to the Niagara Falls, N. Y., plant within the past three months: Dr. Sterling Temple, Dr. B. S. Lacy, Dr. A. M. Muckenfuss, Dr. J. F. Reichert, Dr. C. J. Wernlund, A. T. Hawkinson, A. W. Rudel, J. M. Wainscott, H. A. Bond, P. M. Paulson, M. Marean.

◆ ◆ ◆

Steel Founders Set Meeting Dates

At a meeting of the Board of Directors, Steel Founders' Society of America, Inc., held in Chicago, September 16, the following meetings of that organization were scheduled:

October 22, 1931—Hotel Roosevelt, New York, N. Y.
December 10, 1931—Hotel William Penn, Pittsburgh, Pa.
January 21, 1932—(Annual Meeting), Chicago, Ill.

Use of BISMUTH

BY WALTER

FUSIBLE alloys have been used to some extent in metal forming operations but the potential possibilities of these alloys are not generally appreciated. All of the very low melting alloys contain approximately 50% of bismuth and this high bismuth content imparts non-shrinking properties to the alloys.

The bismuth-lead eutectic contains approximately 58% bismuth and its melting point is 125° C.

Alloys approaching the eutectic composition are used for heat treatment and constant temperature baths in preference to alloys containing tin and cadmium because—first, the bismuth-lead alloys exhibit less tendency to "tin" metals than do the alloys containing tin and cadmium; second, any dross formed by oxidation of the bismuth-lead bath can be effectively reduced by means of charcoal in crucibles and the resulting rubber and vulcanized in hot presses, the core being then removed from the finished article in liquid condition. Adjustment of the alloy composition permits variation of time and temperature factors. Bismuth-lead alloys are also used as a medium of heat transfer and to supply the pressure required for a new process of continuous tank and conveyor type of vulcanization of rubber-covered articles now under development.

The ternary bismuth-lead-tin eutectic contains approximately 52% bismuth, 32% lead and 16% tin and melts at 96° C. The melting point of ternary alloys can be varied over a very considerable range by changing the proportion of the different metals. The ternary alloys are used for low temperature solders, in automatic sprinkler heads, fusible links for fire-door release, alarms, safety plugs and fuses. They are

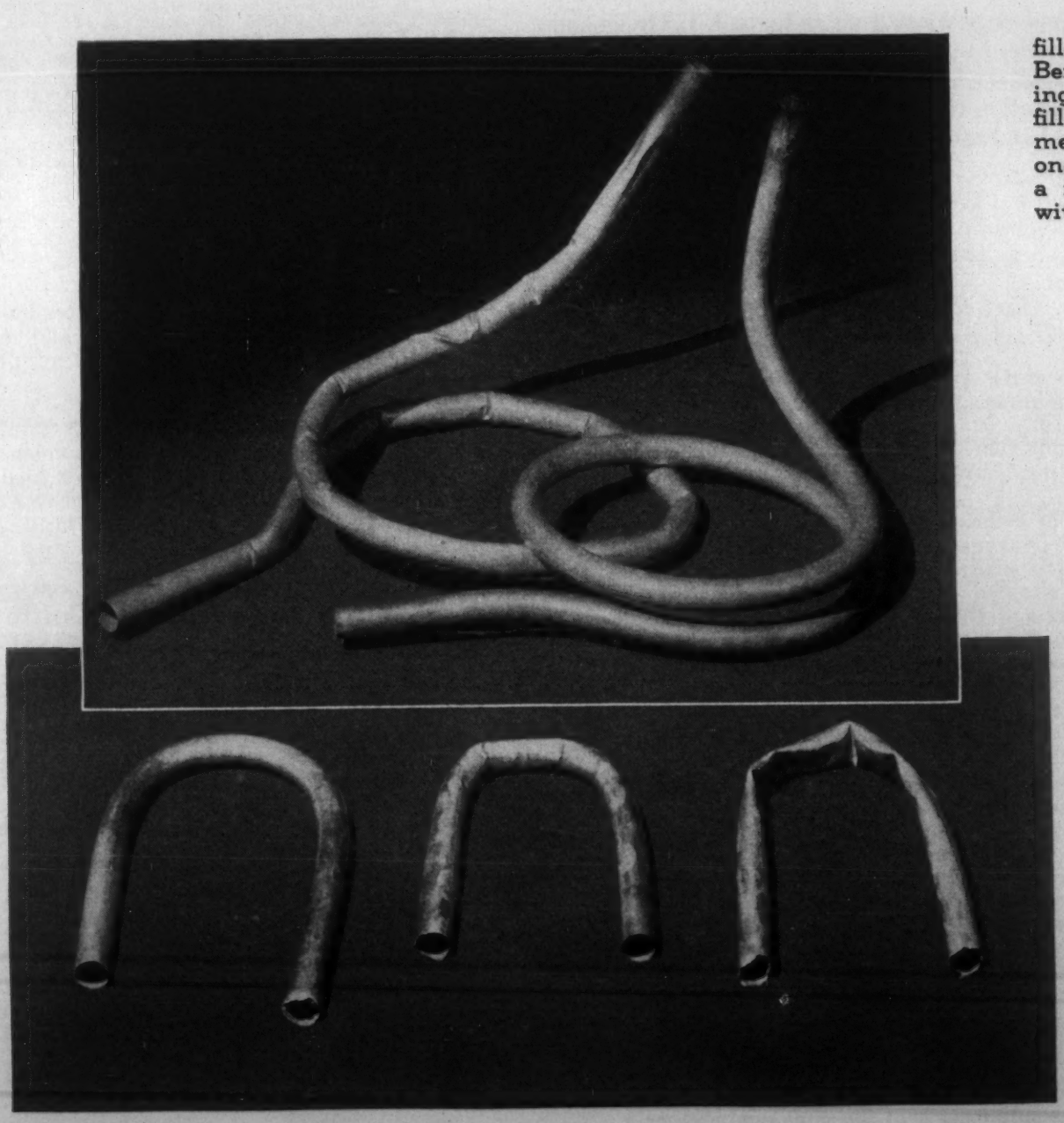


Fig. 1. Bending Thin-Walled Tubing. Above, Bends in brass, the kinked section bent with a sand filler, the other with a Wood's metal filler. Below, Bent copper tubings, the first filled with Wood's metal, the second with sand as a filler, the last with no filler.

metal returned to the bath without affecting the composition of the bath, which is not the case with the tin and cadmium alloys.

The application of the bismuth-lead alloys to rubber vulcanization is under development and offers considerable promise. Cores of the fusible alloys are covered with raw

also used for constant temperatures and tempering baths and for dental modeling.

The quaternary alloys of bismuth, lead, tin and cadmium, approximating the eutectic, are usually known as Wood's or Lipowitz metals. The eutectic has a melting point of 70° C. The literature contains numerous references which give the melting point of the quaternary eutectic as low as 60° C. but

* Metallurgist, Cerro de Pasco Copper Corporation.

in Metal Forming

C. SMITH*

melting points below 70° C. are questionable. A typical Wood's metal contains 50% bismuth, 26.7% lead, 13.3% tin and 10% cadmium.

Woods metal is used for low melting solder, as a pattern alloy, for sprinkler tips, for safety plugs in compressed gas cylinders, as the fusible element in fire-door release and alarm apparatus. Woods metal wets glass and this property is utilized in making gas-tight seals between glass and metal. Wood's metal makes an ideal filler in forming and bending thin wall tubing. Fig. 1 shows bends made with brass and copper tubing with Wood's metal as compared to those made with a fine sand filling. The tubing was filled with molten Wood's metal, cooled, bent to the desired shape and the alloy separated from the tubing by heating in boiling water, a steam bath or by means of a blowtorch. The alloy does not stick to or "tin" the tubing unless fluxes are used. Wood's metal can be used repeatedly provided it is not overheated.

A quaternary alloy composed of 48% bismuth, 28.5% lead, 14.5% tin and 9% antimony and known as Matrix Alloy has been developed by one of the large electrical manufacturing companies, particularly for mounting dies and punches. This alloy is hard and strong, has very little elongation yet has a fairly low melting point. Prior to the development of Matrix Alloy type metal, hard leads, solder, Wood's metal and sulphur were tried but were not satisfactory. Table No. 1 gives comparative properties of some of these alloys.

Type metals, hard leads and solders had too high melting points, too much shrinkage and would peen under the shock of the punching operations and allow the die parts to shift. Wood's metal failed because it was too soft and would peen badly. Sulphur failed in service by flaking and crumbling. The Matrix Alloy has a higher melting point than Wood's metal but its melting point is well below the temperature which endangers the temper of the hardened die parts.

EVERY material with peculiar properties has uses that depend on the utilization of those properties. Bismuth has the property of alloying with a few other metals to form alloys of very low melting points. Some uses of such alloys, based on this unique property, are described below.

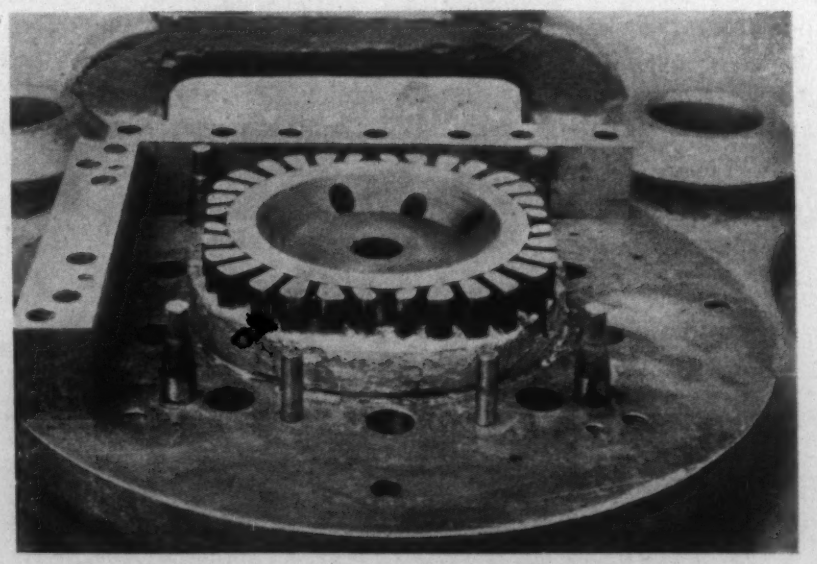


Fig. 2. Matrix Alloy Mounting of a Punch for Stamping Motor Laminations.

Fig. 2 shows a typical Matrix Alloy mounting of a punch for stamping motor laminations. This particular die is made up of 32 separate punches, each held by a single locating screw in the bottom and then locked into position by pouring the Matrix Alloy around the punches. A broken punch can be readily replaced by melting out the Matrix Alloy surrounding the broken part, substituting a new punch and pouring a patch of Matrix Alloy.

Matrix Alloy is an ideal metal for the production of models and templets for the Keller die sinking machines as it can be cast in green plaster Paris molds, does not shrink, is hard and strong. These same properties make Matrix Alloy a very superior metal for the production of dental models, particularly for partial plate and bridge fabrication.

An interesting use of the fusible alloys, while not related to metal-forming industry, is in the measurement of the temperatures in very deep oil wells. A series of cones cast of different alloys having known melting points of suitable range are mounted in a container and lowered in the well. The temperature in the well is indicated by the melting point of the highest melting cone found to have been melted, when the container is pulled from the well. High mercury alloys melting as low as 58.6° C. are used at the lower end of these series. These high mercury alloys have very low tensile strength but are strong enough for this purpose.

Bismuth electroplate has not been given sufficient consideration. Bismuth can be electroplated readily from acid chloride, acid fluosilicate and organic sulphonate electrolytes. The plated surface is bright and can be polished easily to a brilliant finish. The bright surface tarnishes readily to an old pewter appearance. The coating is unusually resistant to atmospheric corrosion.

Table 1.—Physical Properties of Some Type Metals, Solders, Hard Leads, Wood's Metal and Matrix Alloy

Alloy	Percentage Composition					Tensile Strength lbs./in.²	Brinell Hardness	% Elongation	Freezing Temp. °F.
	Bi	Pb	Sn	Cd	Sb				
Hard Lead	..	90.0	..	..	10.0	8,220	17	17.0	486
Hard Lead	..	85.0	..	..	15.0	9,000	17	11.7	476
Linotype	..	84.0	4.4	..	11.5	11,700	21	9.0	476
Sterotype	..	80.2	6.5	..	13.0	12,000	22	4.0	468
Solder	..	60.0	40.0	..	..	6,890	11.8	117.0	464
Solder	..	50.0	50.0	..	..	6,400	11.1	96.0	421
Matrix	48.0	28.5	14.5	..	9.0	13,000	19.0	1.0	248
Wood's	50.0	26.7	13.3	10.0	..	5,990	9.2	140.0	158

◆ ◆ ◆

Steel Foundry Industry Statistics

The Steel Founders' Society of America, Inc., has just developed and published a booklet entitled "Some Statistics on the Steel and Alloy Foundry Industry," containing tables and comparisons on the production and equipment of steel foundries in the United States and Canada.

It is reported to be the most reliable and up-to-date information of its kind relating, as it does, exclusively to the foundry branch of the steel business.

Copies of the booklet may be obtained from the Steel Founders' Society of America, Inc., 420 Lexington Ave., New York City.

A New Aluminum Alloy*

BY T. W. BOSSERT† AND J. A. NOCK, JR.†

Cleveland Municipal Stadium, in construction of which extensive use has been made of 4S alloy. (Walker & Weeks, Architects.)

RECENTLY, the Aluminum Company of America developed and placed on the market a new wrought aluminum alloy* developed by its Research Laboratories at New Kensington. It is now available in the form of sheet, plate, rod, bar, wire, extruded and rolled shapes; in any form, in fact, in which other standard alloys can be obtained.

The alloy was developed in order to round out the series of alloys produced by the company. At the one end of this series are the two materials, commercially pure aluminum (2S) and aluminum manganese alloy (3S), whose tensile strengths in the annealed condition are about 12,000 and 16,000 lbs./in.², respectively. These two materials possess high corrosion resistance and excellent workability. At the other end of the series are the strong aluminum alloys, susceptible to heat treatment with tensile strengths ranging from about 35,000 to 60,000 lbs./in.² Neither the workability nor the corrosion resistance of these alloys are as favorable as those of 2S or 3S. An alloy with a strength in the annealed condition midway between 16,000 and 35,000 lbs./in.², but with workability and corrosion resistance similar to these characteristics in 2S and 3S will meet an important need and find wide application.

The new alloy, termed 4S, which contains about 1% each of manganese and magnesium as added constituents, meets this need. It is not susceptible to heat treatment and cold working is relied upon to produce the desired improvements in mechanical properties. It may be classed as a medium strength alloy, and is available in the annealed temper and in various cold-worked tempers up to the full-hard condition. Combined with this property is a corrosion resistance similar to that of commercial aluminum or that of the aluminum manganese alloy (3S), and workability which is superior to that of the "high strength" aluminum alloys but only slightly inferior to that of the aluminum manganese alloy (3S). The tensile properties of 4S are given in Table 1.

Table 1.—Tensile Properties of 4S Alloy

Temper	Tensile Strength lbs./in.²	Yield Point[1] lbs./in.²	Elongation % in 2″
Annealed	26,000	10,500	20
1/4 Hard	31,500	28,000	5
1/2 Hard	34,500	32,000	5
3/4 Hard	39,000	34,000	3.5
Hard	43,000	39,000	3

[1] Yield point is the stress at which the stress-strain curve shows a departure of 0.2% from the initial modulus line produced.

Table 2.—Miscellaneous Mechanical Properties of 4S Alloy

Temper	Hardness Brinell[1]	Shore[2]	Rockwell[3]	Shear Strength[4] lbs./in.²	Min. Bend Dia.[5]
Annealed	45	14	*E*-50,*S*85	16,000	0T
1/4 Hard	60	21	*E*-74,*S*99	18,000	1T
1/2 Hard	65	23	*E*-79	19,500	2T
3/4 Hard	73	26	*E*-85	22,000	4T
Hard	79	30	*E*-89	23,000	Difficult to bend

[1] 500 kg. load on 10 mm. ball.
[2] Magnifier hammer.
[3] Prefix *S* indicates 60 kg. on 1/8″ ball, prefix *E* indicates 100 kg. on 1/8″ ball.
[4] Single shear strength values obtained from double shear tests.
[5] Diameter over which specimen will bend 180° without failure. T = thickness of specimen.

The yield strengths of all except the annealed tempers of the alloy are noteworthy. In the 3/4 hard and hard tempers, the yield strengths of 4S are comparable to those of the "high strength" aluminum alloys. The properties of the harder tempers of 4S, together with its favorable workability in the annealed temper, indicate its possibilities for formed articles which require a workable material for the forming but which must be stiff and resist permanent deformation. It is also indicated that the alloy will find use in those applications where resistance to denting, etc., is required.

Table 2 lists the hardness values, shearing strengths and minimum bend diameters of the various tempers of the alloy. The compression and compressive yield strengths of 4S in the various tempers are similar, respectively, to the tensile strengths and tensile yield points and are, therefore, not included in Table 2.

It is of interest that the fatigue or endurance limit of this

* This alloy is covered by U. S. Patent No. 1,797,851, dated March 24, 1931.

† Aluminum Company of America.

alloy is exceptionally high, for it has been found to be in the neighborhood of 14,000 lbs./in.^{2} Cold working further raises the endurance limit by only a small amount, so that the hard temper has a value slightly above 15,000 lbs./in.^{2} This alloy, with its combination of high endurance limit and workability, should have many interesting uses. One of the most promising applications suggested is for automotive and aircraft fuel lines, where vibration is often severe, and where the tubing is subject to bending and distortion. The employment of 4S for fan blades and similar uses is also brought to mind.

The alloy 4S can be welded by torch, carbon and metallic arc, and it can be electrically butt or spot welded. Of the first three methods, torch welding is preferred today, because a sounder weld can be made than by the carbon or metallic arc.

Many other characteristics of the alloy are of further interest, such as the readiness with which oxide coatings and metal electro plates may be applied, its consistently fine grain structure, etc., but the important features mentioned should be sufficient to give a clear picture of its properties. The high corrosion and weather resisting characteristics of the alloy, together with the high strengths, etc., attainable by cold working, will probably open the door to applications where lack of either one of the above characteristics had previously barred the way to aluminum.

Probably the outstanding application of 4S alloy is in the new Cleveland Municipal Stadium. This structure is one of the largest stadia in the country, with many new features incorporated in its construction. More than 130,000 pounds of 4S alloy were used, and this alloy was selected because of its corrosion and weathering resistance, its favorable physical properties and its resistance to permanent deformation under heavy wind loading.

The stadium has a ground area of 710 × 800 feet. In general the exterior wall of the egg-shaped structure is composed of brick and aluminum. The wall is of brick up to the first setback, which is at the 86-foot level. Above this there are two elevations composed of aluminum. The lower elevation is 13 feet high and the upper elevation is 26 feet high.

The walls and end sections consist of a continuous series of aluminum pilasters, 14 feet on centers. Between each pair of pilasters, there are three panels of louvres, separated by mullions. No. 20 gage sheet was used in the construction of louvre blades and mullions, and No. 18 gage sheet in the fabrication of the pilasters.

The façade is capped by means of a herring-bone frieze built up of sheet aluminum sections. In line with the use of aluminum in the wall construction, is the adaptation of this metal in the marquise and column enclosures. Incidentally, the bridge panels in the bridge approaches are made from cast aluminum alloys and the bridge railings from strong aluminum alloy tubing.

An application of this magnitude entails the employment of a large number of the operations entering into the metal workers' art, and the satisfactory results produced by the erectors, The Reister and Thesmacher Company, are in themselves definite proof that the new alloy lends itself readily to such operations.

With very few exceptions, crimped sheet was used throughout, and it was necessary to form the sheet in the crimped form. A great deal of the material was formed 90° over relatively sharp radii without fracturing or checking. Many other forming operations, carried out in the erector's plant, were performed successfully. The welding work was carried through without difficulty.

Other applications where this alloy is already finding use are in bus and railway car construction, where it is being used for side and roof sheeting; in the electrical field, where it is being used for light sockets and underground cable sheathing and in the field of fabricated articles, such as washing-machine tub covers, camera parts, ruler edges and trays.

It appears that this new alloy will extend its field of usefulness, because in it have been combined high corrosion resistance, good workability and a strength considerably higher than was heretofore available in an aluminum alloy with the first two desirable characteristics.

◆ ◆ ◆ ◆ ◆

Metallurgical Advisory Board Meeting

The fifth annual open meeting of the metallurgical advisory board to the Carnegie Institute of Technology and the U. S. Bureau of Mines will be held on Friday, October 16, on the Carnegie Tech campus, Pittsburgh.

Progress made on research problems undertaken jointly by Carnegie and the Bureau of Mines will be discussed during the morning and afternoon sessions by investigators from the two laboratories.

Mr. Charles F. Abbott, executive director of the American Institute of Steel Construction, Inc., will be the principal speaker at the evening session which will follow an informal dinner at the Hotel Schenley. Mr. Abbott's subject will be "Market Research in the Steel Industry." Dr. Thomas S. Baker, president of the Carnegie Institute of Technology and organizer of the advisory board, will preside at the evening session.

The morning meeting will be devoted to reports and discussions on iron-manganese-carbon alloys and chrome-nickel alloys. Reports on research work will be given by Dr. Francis M. Walters, Jr., director of the Bureau of Metallurgical Research; Dr. V. N. Krivobok, metallurgist of the same bureau; and Maxwell Gensamer and Cyril Wells, assistants. Dr. C. H. Herty, Jr., physical chemist, and M. B. Royer, assistant metallurgist, of the Bureau of Mines, will deliver a report on the solubility of carbon in iron-manganese-silicon alloys. Dr. G. R. Fitterer, associate metallurgist of the Bureau of Mines will report on the electrolytic method for the determination of inclusions in steel. Other reports will be delivered by the same investigators.

The physical chemistry of steel making will be reported on and discussed at the afternoon session. The three outstanding contributions from this work are the development of a new manganese-silicon deoxidizer, which has been shown to be much superior to ferro-manganese ferro-silicon in combination in producing clean steel at a low cost; the development of a method for quantitatively determining non-metallic inclusions in plain-carbon steels; and the determination of the factors which affect the oxidation of steel in the open-hearth furnace. These reports will be made by Dr. Herty and members of the Bureau of Mines staff.

◆ ◆ ◆

Calendar of Meetings

American Gas Association, Atlantic City, N. J., Oct. 12–16.

National Safety Council, Chicago, Ill., Oct. 12–16.

Gray Iron Institute, 4th Annual Convention, West Baden Springs, Ind., Oct. 15–16.

Steel Founders' Society of America, Inc., New York, N. Y., Oct. 22.

Third International Conference on Bituminous Coal, Pittsburgh, Pa., Nov. 16–21.

American Institute of Chemical Engineers, Atlantic City, N. J., Dec. 9–11.

American Society of Mechanical Engineers, Engineering Societies Building, New York, N. Y., Nov. 30–Dec. 5.

Electrical Resistivity of Certain Copper Alloys in the Molten State*

BY C. S. WILLIAMS†

AS INFORMATION for general use and because of the need for specific data for induction melting calculations, the electrical resistivity of several copper-base alloys in the molten state was measured. A method of extreme accuracy was not needed as the practical usage of the information did not warrant it, so the following method which seemed to combine sufficient accuracy with simplicity and speed of operation was devised.

Basically, the method used was conventional, namely, measurement of the current through and voltage drop along a definite element to determine its resistance. The schematic circuit is shown in Fig. 1. This shows the sample of material to be tested "S," a source of electrical energy for the tests "B," a means of measuring current passing through the sample "A" and a means of measuring the voltage drop across the sample "V."

The current-measuring device was a direct current ammeter capable of indicating currents in a range from 0 to 20 amperes. For voltage determinations, a potentiometer was used since it provided satisfactory measurement of the low voltages (thousandths of a volt) and a null method of measurement (no current flowing in the voltage measuring circuit at time of measurement) which eliminated current errors and reduced the parasitic errors present in the voltage circuit.

The data here presented were secured with the circuit shown in Fig. 2, means being introduced to allow the reversal of current flow through the sample to average out the effects of thermal E. M. F.'s set up in the circuit and to allow the control of current passing through the sample. Reversals were accomplished by the switch system "P" and the current was controlled by the variable resistance "R."

This system was characterized by the use of a large bath of test material in which was submerged a mechanical system to isolate a definite length and cross section of this bath to form a test specimen whose size and shape were known at all times during measurement. The isolation of the sample was accomplished by means of the set-up shown in Figs. 3 and 4. The outer shell is a fused quartz tube and the center portion is a length of two-hole refractory porcelain tubing commonly used as thermocouple wire insulation. Lateral cuts were made in the wall of the porcelain tubing at "E" and "F" to expose the bores at these points, one bore being plugged with refractory cement below the point "E." Two tungsten rods "A" and "B" at these two points provide for connections between the sample and the potentiometer. The two current connections, also tungsten, are shown as "C" and "D." The silica and porcelain tubes serve to define the cross section of metal used as the test sample and the distance from "E" to "F" determines its length.

Fig. 1

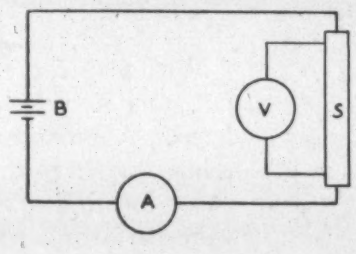


Fig. 2

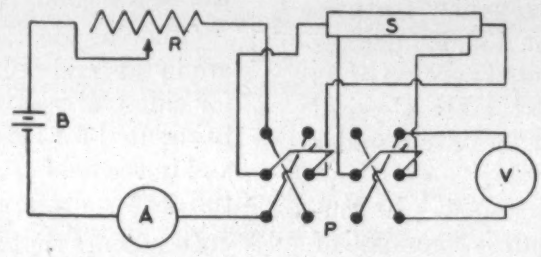
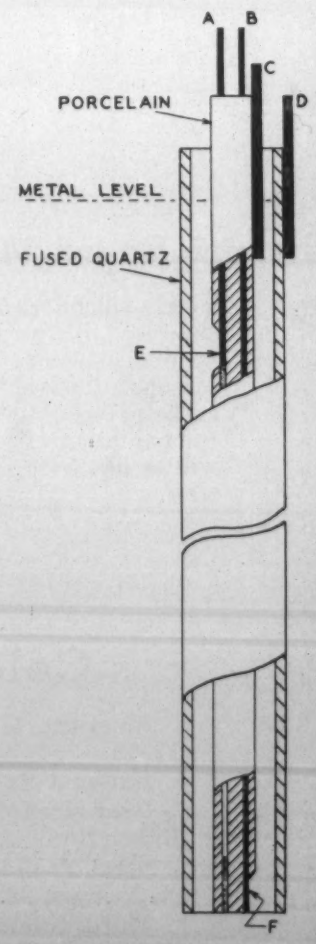


Fig. 3

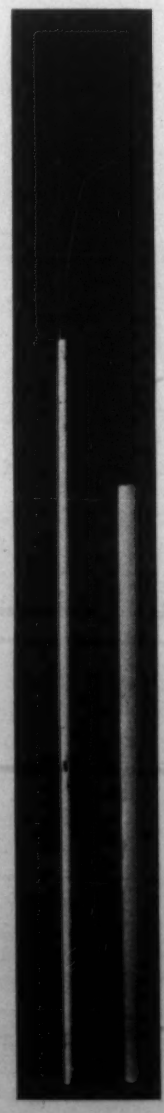


A- } TUNGSTEN RODS
B- } VOLTAGE CONNECTIONS

C- } TUNGSTEN RODS
D- } CURRENT CONNECTIONS

E- } CONTACT POINTS OF
F- } VOLTAGE CONNECTIONS

Fig. 4



Since the internal bore of the fused quartz tubing varies somewhat along its length, calculations of the mean cross section of the sample under test are difficult; hence the calibration of each tube set up was made experimentally. Mercury of known resistivity was used as a liquid in which the units were immersed and observations were made of the current and voltage in this condition. By the use of a standard current for both calibration and tests, the resistivity of the sample became a function of the test voltage.

$$\text{Resistivity of sample} = \frac{\text{Resistivity of Hg} \times \text{Test voltage}}{\text{Calibration voltage.}}$$

Thus actual measurement of sample dimensions became unnecessary.

The test alloys were melted in a graphite crucible holding approximately 20 lbs., heated in an induction furnace. When the desired upper temperature was reached the power was shut off, the melt stirred well and the tube assembly, together with a thermocouple in a fused quartz tube, immersed in the bath. The current through the sample was held at a standard value and simultaneous readings of voltage and temperature were taken at one-minute intervals until the bath had frozen. The power was again applied and when the bath was again molten the tubes were removed and an ingot for chemical analysis and resistivity tests at room temperature was cast from the test bath. The graphite of the crucible provided a sufficiently reducing atmosphere to prevent troublesome oxidation of the metal while molten. Fig. 5 shows the induction furnace used with a crucible beside it, the silica tube assembly being in normal position in the crucible.

As a check on the results obtainable by this method, test runs were made on copper. The values thus found

* Scientific Paper No. 541, Westinghouse Research Laboratories. Presented with the approval of the Westinghouse Electric & Manufacturing Co.

† Westinghouse Research Laboratories, East Pittsburgh, Pa.

were compared with data for the resistivity of copper obtained by E. F. Northrup (*Journal of Franklin Institute*, Vol. 177, 1914). Fig. 6, Curve A, shows Northrup's results and Curve B shows the curve drawn from data obtained by the method just described. With this check on the method it was considered sufficiently trustworthy for the purpose.

For work where the results are required to a higher degree of accuracy, measuring devices of greater precision could be substituted throughout the circuit. Under our conditions, approximately 30 minutes were required to obtain each curve. The time of cooling could be increased, thus giving more points and enabling measurements to be made with greater accuracy.

Figs. 7 and 8 show the resistivity curves of two alloys of each of the systems, copper-zinc and copper-tin. The notations and corresponding chemical analyses follow:

Curve Notation	Chemical Analysis				
	Zn	Sn	Cu	Pb	Fe
19% Zn	18.62	..	80.91	0.02	0.01
13% Zn	12.75	..	86.83	0.02	0.01
4% Sn	0.07	4.14	95.77	0.04	..
2% Sn	...	2.22	97.74	0.02	..

The bracketing curves of the two elements used are shown in each case. The copper curves are from Northrup and the zinc and tin curves are from the Smithsonian Physical Tables. The dotted portions of the curves are segments of straight lines drawn from the lowest points determined, to the resistivity at room temperature in each case.

The most noticeable things about these alloy curves are the long melting ranges and the rounded appearance of the lower knees of these curves as compared with the short melting range and sharp knees in the curves of the pure metals. These two phenomena were observed repeatedly in the course of tests on other alloys.

The slope of the curves above the melting points, in case of the tin alloys, follows that of the copper closely, while that of 13% zinc is inclined more and the 19% zinc less steeply than the copper. The 19% zinc apparently tends toward the peculiarities of the pure zinc which is reported to have a negative temperature coefficient in the lower temperature ranges of its molten state.

THE advent of induction furnace melting of copper and its alloys has made it necessary, for most efficient furnace design, to know one property of alloys in which we formerly had no particular reason to be interested. That is the electrical conductivity of molten alloys. This article describes a simple means of getting such information and cites data on some brasses and bronzes.

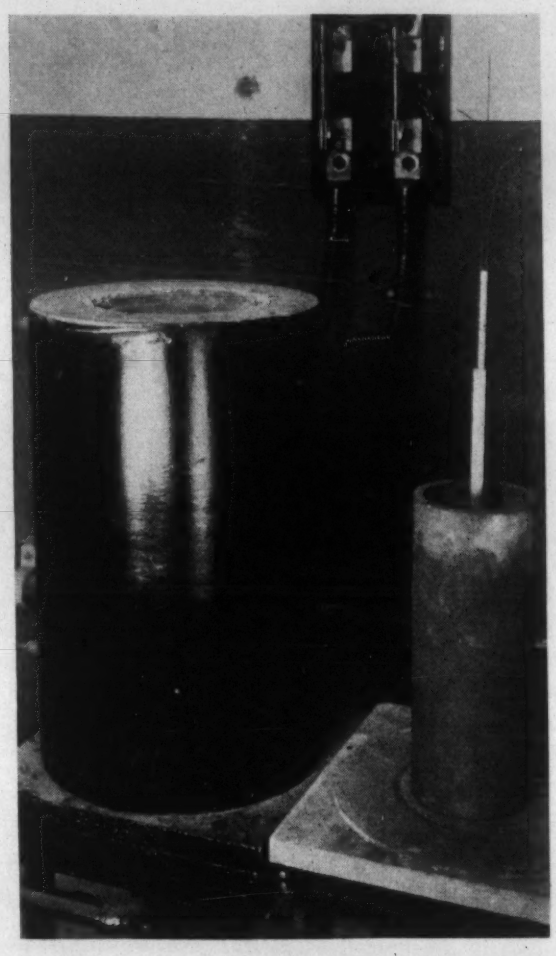


Fig. 5

The curvature of the resistivity-temperature graphs of the alloys in the neighborhood of their melting points is probably due to progressive fusion or freezing as the case may be. The fusion range for the alloys as indicated by the resistivity data are compared with estimates from published equilibrium diagrams in the following table:

	Indicated Fusion Range	Estimated Range from Published Data
13% Zn	1000–1060	1000–1040° C.
19% Zn	900– 990	960–1020° C.
2% Sn	980–1060	1020–1080° C.
4% Sn	990–1050	940–1050° C.

With the exception of the 4% tin alloy, the fusion ranges indicated by resistivity change are wider, the extension of range being on the low end. The maximum deviation between indicated and estimated melting points is 30° C., approximately 3%.

This method seems a quick, sufficiently accurate means of arriving at resistivities in the molten state and could with further precautions be utilized through a lower temperature for such alloys. For alloys with large percentages of low boiling point constituents at high temperatures, difficulty is encountered due presumably to boiling. Such difficulty was experienced with an alloy containing 60% zinc. Metals of considerably higher melting point can no doubt be dealt with by the present method by using the more refractory grades of porcelain now available.

The writer wishes to acknowledge the technical assistance of Dr. P. H. Brace* and the assistance of Mr. H. H. Schmitt* in performing the tests.

* Westinghouse Research Laboratories.

Fig. 6

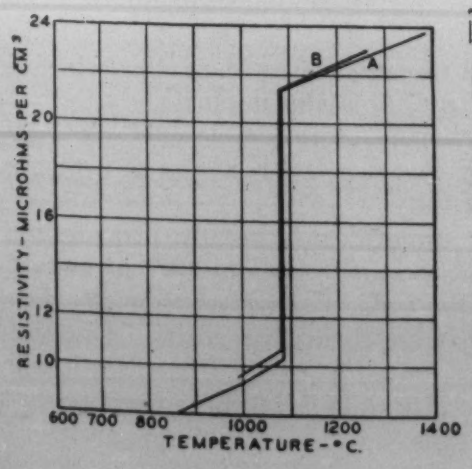


Fig. 7

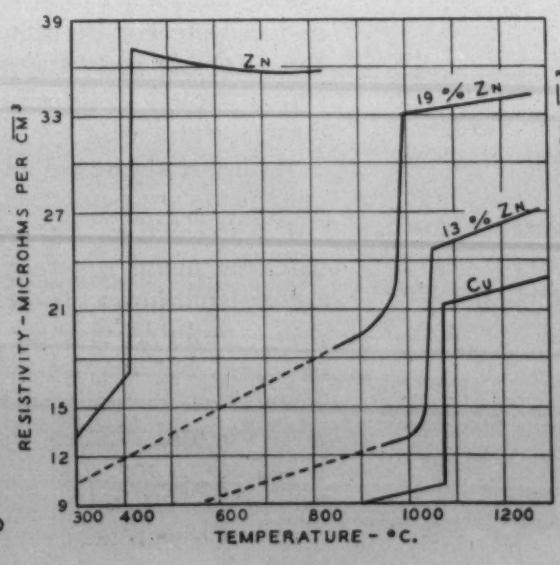
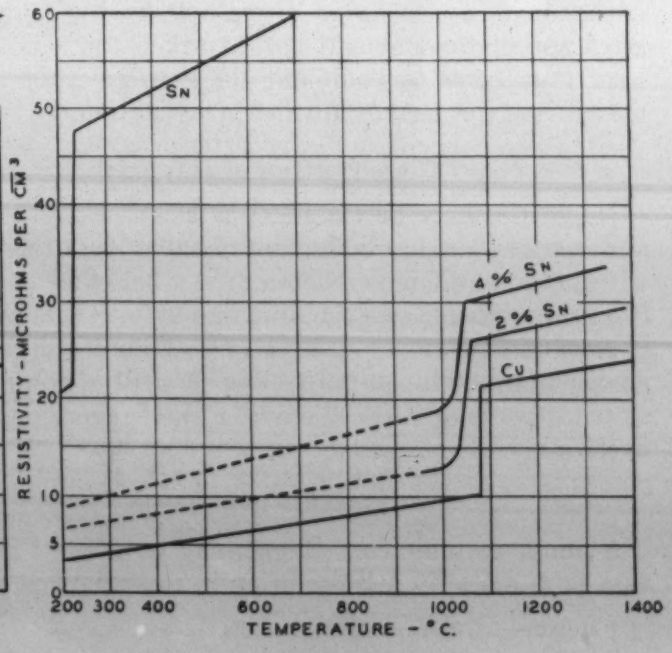


Fig. 8→



The Influence of IMPURITIES in Foundry BRASSES and BRONZES

BY H. M. ST. JOHN*

THE subject of this abstract is somewhat difficult to limit by exact definition. The question: "What is an impurity?" like the similar questions "What is dirt?" or "What is a weed?" might be answered by saying that it is something out of place in its existing location, harmless or possibly even desirable if kept in its proper environment, but undesired where it is. However, this answer is not adequate for our present purpose which is to discuss the influence of minor constituents, whether present by chance or added intentionally. Such minor constituents may be harmless or harmful, depending upon circumstances. If added intentionally they may be beneficial if added in the proper amount and in the proper way, or decidedly harmful if added in excess. For the most part this discussion will be confined to minor constituents which individually amount to not more than 1% of the total alloy composition. In some cases it will be necessary to consider higher percentages because there are no data covering the influence of smaller percentages.

The next question is: "What is a foundry brass or bronze?" American brass foundries melt and cast a multitude of copper alloys of widely varying combinations of copper with tin, lead and zinc, in binary, ternary and quaternary alloys. Other principal constituents of copper alloys are aluminum in the aluminum bronzes, nickel in the nickel silvers and synthetic monels, and sometimes iron, manganese and silicon. Since an adequate discussion of all of these alloys would be an appropriate subject for a volume, it is our purpose to cover more particularly the available data concerning the effect of minor constituents on the structure and properties of the quaternary alloys of copper with tin, lead and zinc, including only such references to the other alloys as may be necessary to indicate possible results in the many cases where data with respect to the quaternary alloys are incomplete.

The incompleteness of the data offers a serious obstacle. The literature is full of information as to the effects of various impurities in copper. A considerable amount of work has been done with the wrought brasses but information dealing with the foundry brasses and bronzes is incomplete and unsatisfactory. The best that can be done in some instances is to trace the influence of an impurity which has been studied with respect to copper, through the variations which have been found to occur when tin or zinc are added, and then speculate as to what may be the result when further principal constituents are included in making up the foundry alloys. Such speculations should not be taken too seriously but at least they serve to point out the gaps in our present information and the need for further investigation.

Classification of Impurities

Impurities may be classified as gases, metallic impurities, and sonims, or insoluble non-metallic impurities. Sonims will not be considered except in cases where they result directly from the presence of a metallic impurity. This classification is convenient but not quite correct theoretically since it includes as a metallic impurity any element or compound, such as phosphorus or cuprous oxide, which is more or less soluble in the alloy.

Metallic Impurities

A minor metallic constituent may be present in an otherwise pure metal in solid solution in the principal metal, as a compound with the principal metal which may or may not be in solid solution, or as an entirely separate constituent, inactive and insoluble. If, instead of one principal metal, we have four, each with its own distinctive relationship to the other three, the behavior of a minor constituent cannot be predicted on a basis of its known behavior with respect to any one of the principal metals, since its most important effect may be to change the relationship already existing between the principal metals. If, in combination with the four principal metals, we have, not one, but three or four minor constituents, the influence of each subject to its relationship with each of the others, the mathematical possibilities become rather awesome. Painstaking work on the part of a few investigators, together with the casual observations of many others, has so far resulted in a very incomplete and imperfect map, with one or two well defined roads and a myriad of devious trails, winding and discontinuous.

Soluble Metallic Impurities

If a minor constituent is completely soluble in the dominating principal metal (in our case, copper) it cannot be identified under the microscope but may exert an important influence on the physical properties of the alloy. It is likely, among other things, to modify the grain size and change the critical temperature at which the metal can be recrystallized by annealing. It may also affect the solubility of the other principal metals in the dominating metal (copper) and thus change their phase relationship. In a cast metal the structure depends upon the rate at which crystal nuclei form as the molten metal cools, and upon the velocity of crystal growth. Both of these factors may be strongly influenced by the presence of an impurity, or a combination of impurities, even though in minute quantities.

When the minor constituent is only slightly soluble its influence is likely to be variable because of other factors tending to promote or retard its solution. If entirely in solution its effect may be negligible, while it may be very harmful if present as a separate phase or in combination with other impurities.

Insoluble Metallic Impurities

An insoluble impurity is necessarily present as a separate phase which may segregate along the grain boundaries or be dispersed throughout the body of the grains themselves. The character of its distribution, as well as the shape and continuity of the particles in which it occurs, will have a pronounced effect on the influence of the impurity. In many cases the insoluble constituent also seems to retard the normal crystal growth of the alloy during solidification, and thus reduces the grain size.

With due allowance for numerous exceptions, the following statements are generally true of metallic impurities:

1. Metallic constituents which form simple solid solutions[1] with the metal generally increase the hardness and tensile strength but lower the ductility.

2. Insoluble metallic impurities[1] generally increase the hardness, but may seriously impair the ductility of metals. Their effect depends on the type of structure to which they give rise, and whether they are themselves brittle or ductile. If the added metal is distributed as isolated particles it will have less effect on the ductility than if it forms a network surrounding the primary crystals.

* Metallurgist, Detroit Lubricator Co.

3. Intermetallic compounds[1] are characterized by being hard and brittle, and frequently appear as well developed crystals embedded in or between the grains of a metal or alloy. Their general effect is to increase the hardness but to lower both the ductility and resistance to shock.

The following list of impurities is discussed in alphabetical order without regard to their classification since many of them exhibit a variable behavior.

Aluminum

Percentages of aluminum between 0.5% and 2.0% added to the true brasses (containing no lead or tin) greatly increase the tensile strength and yield point but decrease the elongation and drawing ability.[2, 3, 4, 24]

It is well known to the brass foundryman that the presence of aluminum causes a thin film of aluminum oxide to form over the surface of his molten brass, restricting the evaporation of zinc and giving the metal a characteristically peculiar appearance. In the mold this film forms a dross which causes pits in the surface of the resulting casting and, in castings of thin section which must withstand a pressure test, results in a high percentage of leakers. Thews[24] suggests that this difficulty may be overcome by bottom pouring and that the addition of phosphor-copper helps because it causes the oxide dross to float. In ingots, traces of aluminum as small as 0.001% to 0.003% may be detected by noting the characteristically smooth areas which appear at various points on the surface.[3]

In leaded brasses and bronzes, very small percentages of aluminum impair the surface color, cause segregation of the lead, and increase the size of grain, tending to make the alloy weak and brittle.[3, 21] As little as 0.05%, or even less, is detrimental to the structure.[21]

Brass alloys containing 2% nickel, 1% aluminum, may be hardened and greatly strengthened by quenching from 800° C. and annealing at 350° C.[18]

Antimony

Working with copper containing less than 0.02% oxygen, Archbutt[26] finds that antimony increases the strength of copper without noticeably affecting the ductility, up to a limit of about 0.47% antimony, below which point thin sheets can be hot rolled. Between 0.47% and 0.85% antimony, copper is hot short but can still be cold rolled. On the other hand, Smithells[1] considers that antimony has a bad influence on copper and its alloys, stating that brass is practically unworkable if it contains as much as 0.005% antimony.

In the foundry alloys Vickers[5] states that substantial percentages of antimony produce brittleness but can be substituted for part of the tin if no great strength or ductility is needed.

The powerful affect of antimony on the structure of copper, and presumably of the copper alloys, may be inferred from the fact that 0.06% antimony raises the recrystallization temperature of pure copper 75° C.[1] Less than 0.2% antimony has a very noticeable affect on the structure of a foundry brass containing 10% lead.[22]

Arsenic

Arsenic is soluble in copper up to 7.25%[1] and, in the absence of oxide, is without noticeable affect up to 0.05%, above which point it tends to reduce the grain size.[1] Copper low in ductility because of the presence of a film of Cu_2O between the grains may be corrected by the addition of arsenic, up to the addition of 1 or 2% arsenic to compensate for 0.1% oxygen.[1]

In wrought brass containing no beta, traces of arsenic do no harm but as little as 0.12% arsenic may reduce the ductility of 60:40 brass by 50%.[1]

Lewis[13] recommends the use of 0.06 to 0.08% arsenic in foundry brass, stating that it makes the molten metal more fluid and results in cleaner and more ductile castings.

Beryllium

This element is not likely to be found in brass as an accidental impurity unless and until such time as the copper-beryllium alloys come into more general use. Alloyed with copper it results in a metal which can be hardened and strengthened by quenching and annealing.[17] The addition of phosphorus accelerates this age-hardening process and causes it to take place at a lower temperature.[20] Nothing is known as to the affect of beryllium in foundry brasses.

Bismuth

The solubility of bismuth in solid copper is not greater than 0.002%, any excess appearing as a second constituent.[1] For this reason bismuth has a very determental effect on the mechanical properties of wrought brass and copper, owing to its intrinsic brittleness and habit of segregating at the grain boundaries. Not more than 0.05% can be tolerated in metal which is to undergo work, while anything above 0.005% is distinctly undesirable. It is probable that the presence of bismuth in cast brass is almost equally objectionable if good mechanical properties are required.

Cadmium

Up to 0.5% cadmium has little or no affect on cast brass[6] but above that point excess cadmiun separates out as a film in the grain boundaries, reducing the resistance of the metal to shock and rapidly decreasing the ductility.

Chromium

There seems to be no published information covering the influence of this element on copper or brass, perhaps for the reason that, until recently, chromium was never found in brass and no one thought of putting it there intentionally. Now chromium-plated brass is beginning to come back as secondary metal and brass foundrymen have a brand new problem. Numerous complaints are heard that brass castings containing chromium as an impurity cannot be machined, although definite data are lacking as yet. The secondary smelters and refiners will probably find, also, that chromium is very difficult to eliminate.

Cobalt

In general the influence of cobalt appears to be beneficial.[7,12,31] According to Iitsuka[7] beta brass is improved in all properties by the addition of cobalt, while alpha brass suffers somewhat in ductility but is otherwise benefited. Browne[12] states that 0.5% cobalt improves the mechanical properties of certain brasses and bronzes while according to Thews[30] the addition of 0.5% cobalt to 88:10:2 increases the tensile strength, elastic limit and elongation in the neighborhood of 10 to 20%.

Combined with silicon, cobalt forms a copper alloy[17] which can be age-hardened.

Iron

Iron has a bad reputation with brass foundrymen probably because it is 4.0% soluble in molten copper at 1100° C. but only 0.2% soluble in solid copper at 750° C.[1] The excess, of course, separates out as a separate constituent but fortunately does not segregate at the grain boundaries and consequently does not greatly impair the mechanical properties. Up to 1 or 2%, iron is deliberately added to 60:40 brass when very hard metal is desired.[1, 2, 4] Thews[30] thinks the value of iron in cast brass is rather doubtful although he says it is supposed to improve the pouring properties and eliminate blow holes. General experience would seem to indicate that less than 0.30% should be present in most cast alloys and less than 0.20% would be better yet.

With silicon, iron forms a copper alloy which can be age-hardened.[17]

Magnesium

Magnesium does not form solid solutions with copper but separates out as Cu_2Mg. According to Smithells[1] its effect on the mechanical properties of copper are so bad that it cannot be used as a deoxidizer. While this may possibly be true with respect to copper, evidence is accumulating to indicate that magnesium may turn out to be a very useful deoxidizer for foundry brass and bronze.

With silicon, magnesium forms a copper alloy which can be age-hardened.[17]

Manganese

The addition of manganese to 60:40 brass, up to 2.8%, increases both the yield point and the tensile strength but greatly decreases the ductility.[4] In foundry bronze small quantities do no harm[30] but above 1% all mechanical properties suffer.

With silicon, manganese forms a copper alloy which can be age-hardened.[17] Alloys of copper with silicon up to 3% and manganese up to 1% are very resistant to corrosion by most acids and many other liquids.[19]

Nickel

This element is completely miscible with copper in all proportions and at all temperatures. It is also completely miscible with the alpha constituent of copper-zinc alloys but greatly modifies the alpha range of copper-tin alloys.[28] In the latter case it causes the eutectoid constituent to separate out at lower and lower tin contents as the nickel content increases. With 1 % or more of nickel there is evidence of a dispersed constituent in the alpha phase,[27] resulting in an increased hardness of the alpha up to 5% nickel. The hardness of the eutectoid seems to decrease at first but increases again above 0.5% nickel, equalling the original hardness at 2.0% nickel and continuing to increase up to 5% nickel.

Guillet[11] states that brass containing a little nickel is easier to cold work but that nickel suppresses the beta constituent and makes it very difficult to hot work brass which normally contains only a little beta.

In foundry brasses and bronzes, nickel may be substituted for a substantial proportion of the tin without much change in the structure and without impairing machinability.[28] There is even some improvement in mechanical properties due to the fact that nickel densifies and refines the grain in heavy sections, when used in amounts varying from 0.5 to 2.0%. Nickel raises the melting point of such alloys by 10° or 15° C. for every percent added but, curiously enough, actually lowers the optimum pouring temperature. It has been found that as little as 0.5% nickel permits the pouring of foundry alloys of the 85:5:5:5 type at temperatures 40° or 50° C. lower than is normally the case with nickel-free alloys.

The influence of nickel in holding lead in a dispersed state in high-lead bronzes is well known but it is not so well known that this effect practically disappears when substantial percentages of zinc are present and the tin content is relatively low. It is probable that dispersion of the lead is really due to the tin eutectoid constituent and that the effect of nickel is merely to increase the proportion of this constituent. Zinc, in somewhat larger proportions, accomplishes the same result to such an extent that a further addition of nickel is without effect.

The pronounced tendency of nickel to reduce the average grain size in foundry brasses is effective in overcoming the coarse, dendritic grain growth due to the presence of small quantities of aluminum or silicon[22] although 2.0 to 3.0% of nickel is necessary to offset the effect of 0.05% silicon.

Nickel combined with silicon[17] or with aluminum[18] forms age-hardening alloys with copper.

Oxygen

Oxygen in copper and brass is probably present in the form of oxides only. While the influence of Cu_2O in copper has been extensively studied, very little is known regarding the effect of oxides in brass, other than the very general fact that brass melted under severely oxidizing conditions is subject to sluggishness in pouring and reduced strength in the cast metal.[21] In melting brass or bronze badly contaminated with impurities atmospheric oxygen is the most effective refining agent known, subject to the disadvantage that it causes loss of zinc and, to some extent, of the other principal constituents.

Phosphorus

The use of phosphorus as a deoxidizing agent in foundry brasses is, of course, well known. There is some prejudice against its use in alloys containing more than 10% zinc but ill effects in such cases are probably due to failure to completely remove the dross which is formed.[29] Excessive phosphorus is likely to cause segregation and tin sweat in the tin-lead bronzes but in quantities of from 0.03 to 0.05% in the finished metal there is little to be feared.[30] Similar proportions may be tolerated in foundry red brass.

Silicon

Silicon is fairly soluble in copper and forms useful alloys with it,[8, 17, 19, 23 25, 30] increasing the hardness and strength of both copper-zinc and copper-tin alloys. It has already been mentioned under manganese that 1% of silicon, with 3% of manganese, forms with copper an alloy which is exceptionally resistant to corrosion.[19] Silicon, in combination with any one of a number of other metals, forms with copper alloys which can be usefully age-hardened.[17]

However, in brass foundry alloys silicon is a most undesirable impurity, to be avoided at all costs.[21, 22, 25, 30] It unites with lead to form a foamy dross which can hardly be eliminated and which results in castings of unsightly appearance and poor performance on pressure tests.

The influence of silicon on the structure of copper alloys containing lead in combination with both zinc and tin is even more serious. Although it seems to be entirely in solution in the alpha constituent, very small percentages of silicon result in a very coarsely dendritic crystalline growth with large intercrystalline fissures and, in general, a porous, weak structure.[21, 22] As one natural result, the lead in such alloys is badly segregated. In an alloy containing 10% of lead, 0.03% silicon is sufficient to cause trouble[22] while, with lead at only 2%, 0.05% silicon results in unsatisfactory castings.

That the detrimental effects of silicon are based principally on its influence on crystal growth is indicated by the fact that the difficulty is not apparent in chill-cast metal and is greatly minimized in sand castings poured at low temperatures.[22] The influence of nickel in reducing the bad effects of silicon has been mentioned under the discussion of that element. It seems probable that sulphur has a similar effect.[22] In other words, any alloying constituent or any operating condition which tends to promote small crystal growth more or less effectively offsets the tendency to produce coarse crystals and a weak structure.

Sulphur

There is a difference of opinion[1] as to the effect of small percentages of sulphur in copper. This difference becomes even more pronounced in the case of the foundry copper alloys. However, it is beginning to seem fairly clear that sulphur is beneficial, harmless or harmful depending upon the nature of its combination with the principal constituents or with other minor constituents which may be present.

As sulphur dioxide, sulphur is undoubtedly harmful. This will be more fully discussed under gases. Cuprous sulphide may or may not be harmful depending upon its distribution. Most combinations of sulphur with other constituents appear to be relatively harmless, although zinc sulphide may be an exception. So little is definitely known with regard to this exceedingly complicated situation that an attempt to discuss it in detail is rather futile. Sulphur is widely credited with

the ability to hold lead in dispersion in copper-lead alloys and this has been confirmed by Nishimura[9] who found that sulphur between 0.4% and 0.8% had such an effect on a 50:50 copper-lead alloy while smaller or larger percentages exhibited great irregularities of behavior. In default of conclusive evidence maximum tolerances for sulphur in brass or bronze castings are variously placed between 0.05% and 0.10%.[21, 22]

Gases

There is experimental evidence[1] that the volume of gas which can be held in solution by solid copper-zinc alloys is of about the same order as the volume of the metal itself. How far this applies to the foundry brasses is an open question. Gases in solution nearly always have an embrittling effect, causing fractures which follow the grain boundaries. The tendency of gases to diffuse along the grain boundaries, where other minor constituents are most likely to be found, may result in reactions which still further impair the quality of the metal.

The most obvious detrimental effect of gases in castings is due to the evolution of previously dissolved gas during the process of solidification. The amount of gas evolved at this stage may be very considerable, resulting in serious porosity. Since an examination of the defective casting does not serve to identify the gas which caused the trouble, there has been, and still is, much difference of opinion as to the relative effect of the various gases which might be present.

Hydrogen

Hydrogen behaves much like a metal[1] and appears to form solid solutions and intermetallic compounds with the various metals, influencing their properties in much the same way as if it were a metal. It has been largely neglected by the foundryman in his speculations with regard to gas porosity but is, nevertheless, probably the most serious factor to be considered in connection with this particular difficulty.

Guillet,[31] by heating samples of 67:33 and 60:40 brass, obtained from them mixtures of gases ranging in hydrogen content from 36 to 65.5%, which, in every case, was considerably greater than the amount of any of the other gases present.

Carbon Monoxide and Carbon Dioxide

Since these gases are known to be present in all furnace atmospheres, their influence on various metals has been much discussed. According to Smithells[1] the solubility of either of these gases in solid copper is slight, increasing slowly with the temperature up to the melting point. Exactly at the melting point the solubility of the gases is nearly ten times as great in molten copper as it is in solid copper at the same temperature. The evolution of gas during solidification may, therefore, be considerable with a corresponding tendency toward porosity.

In brass Guillet[31] found from 8 to 30% of these two gases combined but there seem to be no data as to their solubility in molten brass. It is presumably less than their solubility in copper but the possibility that they cause porosity by evolution during solidification should not be neglected.

Bolton[21] attributes certain difficulties with bronze castings to the fact that the metal was melted under an atmosphere rich in carbon monoxide. The difficulty in question disappeared when a slightly oxidizing atmosphere was employed. This effect might be due, as suggested by Bolton, to some direct action by the carbon monoxide, resulting in a coarsely crystalline growth with intercrystalline fissures, or possibly to some other unidentified impurity which the reducing atmosphere had no tendency to remove but which was eliminated by an oxidizing atmosphere. It has been shown[22] that sound metal can be produced under a carbon monoxide atmosphere provided detrimental oxidizable impurities are absent. While the point has not yet been definitely proven, it seems possible at least that carbon monoxide has, in this instance, been accused of committing a crime which, as an indifferent bystander, it merely did nothing to prevent.

Nitrogen

Nitrogen is insoluble in solid copper[1] and but slightly soluble in the molten metal. Guillet,[31] however, did succeed in obtaining quite a substantial amount of nitrogen from heated brass. Practically nothing is known about its effect on foundry brass but it probably is not a serious factor.

Sulphur Dioxide

The solubility of sulphur dioxide in solid brass of the 67:33 type increases as the temperature is raised but in the molten alloy is much less at 1100° C. than it is at the melting point.[1] It is rather unlikely that sulphur dioxide is responsible for much gas porosity at the pouring temperatures employed with foundry brass but such sulphur dioxide as is retained in solution is likely to result in undesirable reactions along the grain boundaries as the metal cools. According to Röngten[10] the following irreversible reaction takes place

$$SO_2 + 2\,Cu + Sn = Cu_2S + SnO_2$$

The products of the reaction occupy additional space and, in alloys containing much lead, this still molten metal may be forced out of the casting as an exudation. The expansion of impurities along the grain boundaries also tends to weaken the metal and may even crack it.

List of References

[1] C. J. Smithells. Impurities in Metals. John Wiley & Sons, Inc., New York, 1929.

[2] Anon. Influence of Aluminum, Lead, Iron and Tin in Brass. *Zeitschrift für Metallkunde*, Vol. 21, 1929, pages 152–159.

[3] J. Silberstein. The Effect of Aluminum on Brasses. *Metal Industry*, London, Vol. 34, 1929, pages 5–6.

[4] E. Millington. The Influence of Small Quantities of Some Metallic Elements on the Mechanical Properties of Brass. *Journal Society Chemical Industry*, Vol. 37, 1928, pages 149–155T.

[5] C. Vickers. Antimony in Brass Mixtures. *Foundry*, Vol. 41, 1913, pages 322–323.

[6] W. Bannau. Effect of Cadmium on Mechanical Properties of Brass. *American Metal Market* (Magazine section), Vol. 35, 1928, pages 12–14.

[7] D. Iitsuka. The Effect of Mixing Small Quantities of Cobalt with Brass. *Memoirs College Science Kyoto Imperial University*, Vol. 12A, 1929, pages 179–198.

[8] C. G. Smith. The Constitution of the Copper–Silicon System. *Technical Publication* No. 142, *American Institute Mining & Metallurgical Engineers*, 1928, 25 pages.

[9] H. Nishimura & S. Ando. Influence of Sulphur on Copper-Lead Alloys. *Suiyokaishi*, Vol. 5, 1928, pages 696–706.

[10] P. Röntgen & G. Schwietzke. The Effect of Sulphur Dioxide on Bronze and Copper. *Zeitschrift für Metallkunde*, Vol. 21, 1929, pages 117–120.

[11] L. Guillet. New Investigations of Nickel Brasses. *Revue de Métallurgie*, Vol. 17, 1920, pages 484–495; *Chemical & Metallurgical Engineering*, Vol. 24, 1921, pages 261–265.

[12] de Courcy Browne. Some Recent Applications of Metallic Cobalt *Transactions American Institute of Metals*, Vol. 8, 1914, pages 61–67.

[13] E. A. Lewis. The Use of Arsenical Copper for Making Cold-Rolled Brass. *Metal Industry*, New York, Vol. 11, 1913, pages 76–77.

[14] O. F. Hudson & R. Dunn. Vanadium in Brass. *Metal Industry*, New York, Vol. 12, 1914, pages 110–111.

[15] J. W. Bolton & S. A. Weigand. Incipient Shrinkage in Some Non-Ferrous Alloys. *Technical Publication* No. 163, *American Institute Mining & Metallurgical Engineers*, 1929, 18 pages.

[16] O. F. Hudson. Constitution of Brass Alloys. *Foundry*, Vol. 37, Aug. 1910, page 33.

[17] J. L. Gregg. Dispersion Hardening in Copper and Silver Base Alloys. *Technical Publication* No. 161, *American Institute Mining & Metallurgical Engineers*, 1929, 7 pages.

[18] T. Tanabe. Investigation of High-Strength Brass. II. *Journal Mining Japan*, Vol. 44, 1928, pages 219–231.

[19] H. A. Bedworth. Resistance of Copper-Silicon-Manganese Alloys to Corrosion by Acids. *Technical Publication* No. 189, *American Institute Mining & Metallurgical Engineers*, 1929, 14 pages.

[20] G. Masing & O. Dahl. Influence of Small Additions of Phosphorus on the Age-Hardening of Beryllium-Copper Alloys. *Wissenschaftliche Veröffentlichungen aus dem Siemens-Konzern*, Vol. 8, Pt. 1, 1929, pages 197–201.

[21] J. W. Bolton & S. A. Weigand. Effect of Oxidation and Certain Impurities in Bronze. *Technical Publication* No. 281, *American Institute Mining & Metallurgical Engineers*, 1930, 17 pages.

[22] H. M. St. John, G. K. Eggleston & T. Rynalski. Influence of Silicon in Foundry Red Brasses. *Technical Publication* No. 300, *American Institute Mining & Metallurgical Engineers*, 1930, 18 pages.

[23] E. Vaders. A New Silicon-Zinc-Copper Alloy. *Journal Institute of Metals*, Vol. 44, 1930, pages 363–380; discussion, pages 381–388.

[24] E. R. Thews. Influence of Aluminum on Technical Brass Alloys. *Canadian Chemistry & Metallurgy*, Vol. 14, 1930, pages 322–323, 325.

[25] H. W. Gould & K. W. Ray. The Effects of Silicon on the Properties of Brass. *Metals & Alloys*, Vol. 1, 1930, pages 502–507.

[26] S. L. Archbutt & W. E. Prytherch. Investigation of the Effects of Impurities on Copper. *Journal Institute of Metals*, Vol. 45, 1931, pages 265–297; discussion, pages 298–305.

[27] C. Upthegrove, G. Wilson & F. N. Rhines. The Effect of Additions of Small Percentages of Nickel to a Copper-Tin Bronze. *Proceedings American Society for Testing Materials*, Vol. 30, Pt. II, 1930, pages 512–519.

[28] N. B. Pilling & T. E. Kihlgren. Some Effects of Nickel on Bronze Foundry Mixtures. *Transactions & Bulletin American Foundrymen's Association*, Vol. 2, 1931, pages 93–114.

[29] J. Silberstein. Phosphorus Causes Hard Spots in Bearing Bronzes. *Foundry*, Vol. 57, 1929, pages 672–675.

[30] E. R. Thews. Alloys Affect Properties. *Foundry*, Vol. 56, 1928, pages 532–535.

[31] L. Guillet & A. Roux. Gases Contained in Brasses, Aluminum and Its Alloys. *Comptes Rendus*, Vol. 184, 1927, pages 724–727.

PREFERRED ORIENTATION PRODUCED BY COLD ROLLING

in the Surface of Sheets of

Aluminum, Nickel, Copper and Silver*

BY CLEVELAND B. HOLLABAUGH** AND WHEELER P. DAVEY***

THE advent of X-ray methods for study of crystal structure made it possible to get definite evidence on the way the crystals arranged themselves on cold-working, and made it plain that such phenomena as the "earing" of cups drawn from severely worked sheet were due to "preferred orientation." From some of the early evidence, it was assumed that a very definite equilibrium position was finally taken up, and it was supposed that all metals of a certain crystal type would act alike.

As is shown in the article below, different metals and alloys really act in a more individualistic manner, and the matter is a bit more complicated than was originally supposed. Upon just what does happen, depend the properties of the sheet, the type of surface obtained, and the necessity for intermediate anneals.

TABLE OF CONTENTS

I. Introduction.
II. Survey of Previous Work on Orientation in Aluminum, Nickel, Copper and Silver.
III. Experimental.
  a. Apparatus Used in this Study.
  b. Samples Studied.
  c. Annealing Treatment of Samples.
  d. Rolling Treatment of Samples.
  e. Technique Used for Securing "Reflection" Type Diffraction Patterns.
  f. Diffraction Patterns Made.
IV. Method and Results of the Interpretation of Diffraction Patterns.
  a. Identification of Diffraction Rings on "Reflection" Patterns.
  b The Determination of the Preferred Ranges of Orientation from Changes in Diffraction Rings on Cold Rolling Aluminum, Nickel, Copper and Silver.
    1. Aluminum.
    2. Nickel and Copper.
    3. Silver.
V. Correlation and Discussion of Data.
  a. Comparisons of Orientations in the Four Metals.
  b. Comparison of These Results with Previous Work.
  c. Significance of Results Presented Here.
VI. Summary of Results.
VII. Acknowledgments.
VIII. References Cited.

I. INTRODUCTION

WHEN a sample of a pure metal in a cast or annealed condition is examined under the microscope, the microstructure presents a polygonal network, indicating that the metal is composed of irregular polyhedral grains. Each of these polyhedral grains is a single allotriomorphic crystal, having a continuous space lattice. The space lattice of the metal as a whole is, however not continuous, since the neighboring grains do not have the same crystallographic orientation.

When a sheet of metal of this structure is cold rolled the individual crystals are strained beyond their elastic limit and undergo rupture, resulting in the production of a large number of crystal fragments. These crystal fragments have a tendency to orient themselves in definite positions which have been termed their preferred orientations.

It is generally recognized that the deformation of the crystals of a metal takes place by a shearing motion along one of the crystallographic planes, the atoms on one side of the plane moving as a unit relative to those on the other side of the plane. This slip will occur along the family of planes of the largest interplanar spacing[1] since the attractive forces between atoms in adjacent planes will be a minimum between these planes. With face centered cubic metals slip occurs on the (111) family of planes.[2] This has been confirmed experimentally on single crystals of aluminum.[3]

Since slippage occurs along the same crystallographic planes in metals having a given space lattice, the crystal fragments of these metals would be forced to assume the same preferred orientation, unless there is another factor influencing the behavior of the crystal fragments. The other possible variable is the field of force holding the atoms of the metals in the crystal space lattices. For a group of metals, showing as varied chemical properties as those crystallizing in the face centered cubic system, it is hardly to be expected that this field of force would be identical from one metal to the next. There seems to be nothing in the literature on how such a variation in the electrostatic binding forces in the lattice would affect the deformation, but it would seem reasonable to expect it to have some effect.

There are numerous statements in the literature, that the preferred orientations assumed by the metals having a face centered cubic lattice are identical, and this fact seems to be generally accepted since the more recent workers have confined their work to a single representative of each space lattice. Some of this recent work[4,5] has shown that a single metal, aluminum is not consistent in showing a single preferred range of orientation. This alone throws doubt on the statement that the different metals having this space lattice always show the same orientation.

The study of preferred orientation is of great importance from two points of view. One is that mentioned above, namely, the possibility of gaining information concerning the lattice forces in the metals. The other is the possibility of explaining the changes occurring in the physical properties of metals on cold working. This second possibility has drawn the attention of quite a few workers since this is perhaps the most important problem in physical metallurgy at the present time. These investigators have shown that the process of cold deformation by rolling is much more complex than originally supposed and that it is not possible at present to set up a satisfactory hypothesis which can be tied in with the slip mechanism in single crystals. The results obtained with cold rolled foil have been contradictory and this lack of agreement has led recent workers to view the conditions of rolling as being of paramount importance.

On this basis it seemed that a determination of the orien-

* Contribution from the Physico-Chemical Laboratories of the School of Chemistry and Physics, The Pennsylvania State College. This paper is based on a thesis submitted by the junior author in partial fulfillment of the requirements for the degree of Doctor of Philosophy at The Pennsylvania State College.

** Hercules Powder Co. Research Fellow.
*** Professor of Physical Chemistry, The Pennsylvania State College.

tations produced when the face centered cubic metals were given similar rolling treatment, should contribute valuable information on this problem.

The purpose of this paper is to present the results of a study of the preferred orientations assumed by crystal fragments of aluminum, nickel, copper and silver when given similar rolling treatment. This study has been carried out using a method[6] by which the crystal orientation may be studied in one surface of a sheet, using the "reflection" type of diffraction. This avoids the difficulty inherent in the transmission method, since the diffraction patterns from the oriented layers of crystals on both sides of the sheet are not recorded at the same time. This avoids getting the sum of two oppositely directed orientations as is gotten when the beam is transmitted straight through the foil.

The data secured show that with each of the four metals there is not a single preferred position, but a range of preferred positions, and that the range of preferred positions is not the same in each case. Nickel and copper show identical orientations both as to limits of ranges or orientations and as to mean positions. Aluminum and silver show related orientations but with widely different angular limits, which in the case of aluminum are dependent on the number of passes through the rolls and in the case of silver are independent of the number of passes. This work shows that except for copper and nickel, the common face centered cubic metals show differences in preferred orientation both with respect to the limits of the preferred range and with respect to the mean position of orientation. The preferred positions are similar only in that they all show that one face diagonal of the cube always lies in a plane which is parallel to the direction of rolling and perpendicular to the rolling surface.

These results demonstrate that the lattice forces in nickel and copper must be very similar, since these two metals show exactly the same range of preferred positions on cold rolling. This is in agreement with the facts that the chemical valence of both is ordinarily two and that they are closely related in their atomic structure since nickel has an atomic number of 28, while that of copper is 29. Aluminum and silver, however, do not behave in the same way, and neither behaves like nickel and copper. This indicates differences in the lattice forces in these metals. This indicated difference is to be expected from the facts of chemical valence and atomic structure. Aluminum has a valence of three, with an atomic number of 13, while silver has a valence of one with an atomic number of 47.

These results show that the deduction of general conclusions regarding this group of metals, from the data obtained from a single individual, is not justified and that the prevalent choice of aluminum as a representative of the series is particularly unfortunate, since its behavior is the most irregular of the group.

Likewise this work shows that with preferred orientation we are not dealing with a single preferred position in any case, but a preferred range of positions. Since, except for aluminum, the angular limits of these ranges of preferred positions are not altered by continued rolling, it is evident that repeated rolling merely increases the probability of a crystal fragment being found in the preferred range. There is no evidence from this work that continued rolling tends to force the crystal fragments to some single preferred orientation.

II. SURVEY OF PREVIOUS WORK

THE lattice structures of aluminum, nickel, copper and silver are well established as being face centered cubic. Hull,[7,8] Scherrer[9] and Kirchner[10] have shown aluminum to have this structure. Nickel has been shown to be face centered cubic by Hull,[11,12] Wever[13] and McKeehan.[14] Copper was placed in this group by the work of Bragg[15] and Kirchner,[10] as was silver by the work of Vegard[16] and McKeehan.[17] Precision measurements of the lattice constants of each of these metals, made by Davey,[18] for samples of varying purity have been used in the calculations made in this work.

Symmetrical diffraction effects from rolled metal foils were first observed by Hupka,[19] who showed them to disappear on heating the foil. In 1920 it was first shown by Uspinsky and Konobejewski[20] that this diffraction effect in cold rolled metals was due to a directed arrangement of the crystal fragments. Shortly afterward it was found by Becker, Herzog, Jancke and Polanyi,[21] that cold drawn wires gave similar diffraction effects. In this paper and in a series[22,23,24,25,26] following the view was developed that these effects were due to the rearrangement of the crystallites of the annealed metal by cold deformation in such a way that the crystallographic axes assumed definite directions in space. The similarity of this arrangement to that found in plant fibers led to its designation of "fiber structure."

The earliest determinations of the crystal orientation produced in metal foils by cold work were those of Mark and Weissenberg.[27,28] These investigators found two independent ranges of orientation in cold rolled foils of silver, aluminum gold, copper and platinum. The first is characterized by the fact that a [112] direction lies parallel to the rolling direction with a scattering of 8° and a (110) plane parallel to the plane of rolling with a scattering of 35°. The second orientation has a [100] direction parallel to the rolling direction with a scattering of 8° and a (100) plane parallel to the plane of rolling with a scattering of 40°. This orientation has been confirmed for silver, copper and aluminum by Glocker and his co-workers in a series of papers[29,30,31,32] dealing primarily with recrystallization.

Owen and Preston[33] found that aluminum showed a definite orientation in which the cube diagonal is in the direction of rolling and a (211) plane is in the plane of rolling. Two sets of orientation were shown to exist in the material after rolling the one set being the optical image of the other in the plane of rolling. They also show that the space lattice of aluminum remains unaltered and that the lattice parameter is unchanged by cold work.

Tanaka[34] studied the effects of cold rolling on a single crystal of aluminum and reported two types of orientation structure. In the first type the rolling direction corresponds to the [110] direction and the (001) planes are nearly parallel to the surface. The maximal deviation from this orientation is about 26° and is produced by a rotation of the crystals about the rolling direction. The second type of structure found, was one in which the rolling direction corresponds to the [112] direction and the (110) plane coincides with the rolled surface. The maximal deviation was about 28°.

Dehlinger[35] has reported that the face centered cubic metals, on severe rolling show identical orientation structures and one in which the [112] direction lies in the rolling direction and the (011) plane is parallel to the rolling plane. This work was done on aluminum, copper, silver, gold and platinum. This result was confirmed for copper by Eisenhut and Widmann.[36]

Konobejewski[37] in a study of the crystal structure of nickel, iron and molybdenum foil, found that in nickel the rolling direction lies in the (110) plane between the [111] and [211] directions, making an angle of 8° with the latter.

Norton and Warren[38] have made a study on the plastic deformation of metals in which they include a study of the cold rolling of the face centered cubic metals. On the basis that the slip producing the preferred orientation occurs on the (111) plane in the face centered cubic metals and that all of these metals behave in exactly the same way, these authors conclude that these metals will show a single orientation position such that the (101) plane is in the plane of rolling and the [112] axis in the direction of rolling.

This theoretical conclusion is then tested experimentally by making a single diffraction pattern of the sample of aluminum having an unspecified rolling treatment. This diffraction pattern is interpreted by the use of the reference sphere and

the following generalization drawn: "The assumed orientation of the grains is fully confirmed and we may conclude that the directional rolling of a face centered cubic metal gives rise to slip on the {111} family of crystallographic planes with a resulting orientation of the grains, so that the [112] axis coincides with the direction of rolling and the (001) plane lies in the plane of rolling."

The derivation of the positions of the experimentally determined atomic planes from those derived from theoretical calculation were investigated in aluminum and were explained with the help of the warping and strain hardening processes observed in a single crystal. Since the parallelepiped deformation is closely related to the process of rolling the authors conclude that the deformation in cold rolling occurs by slip

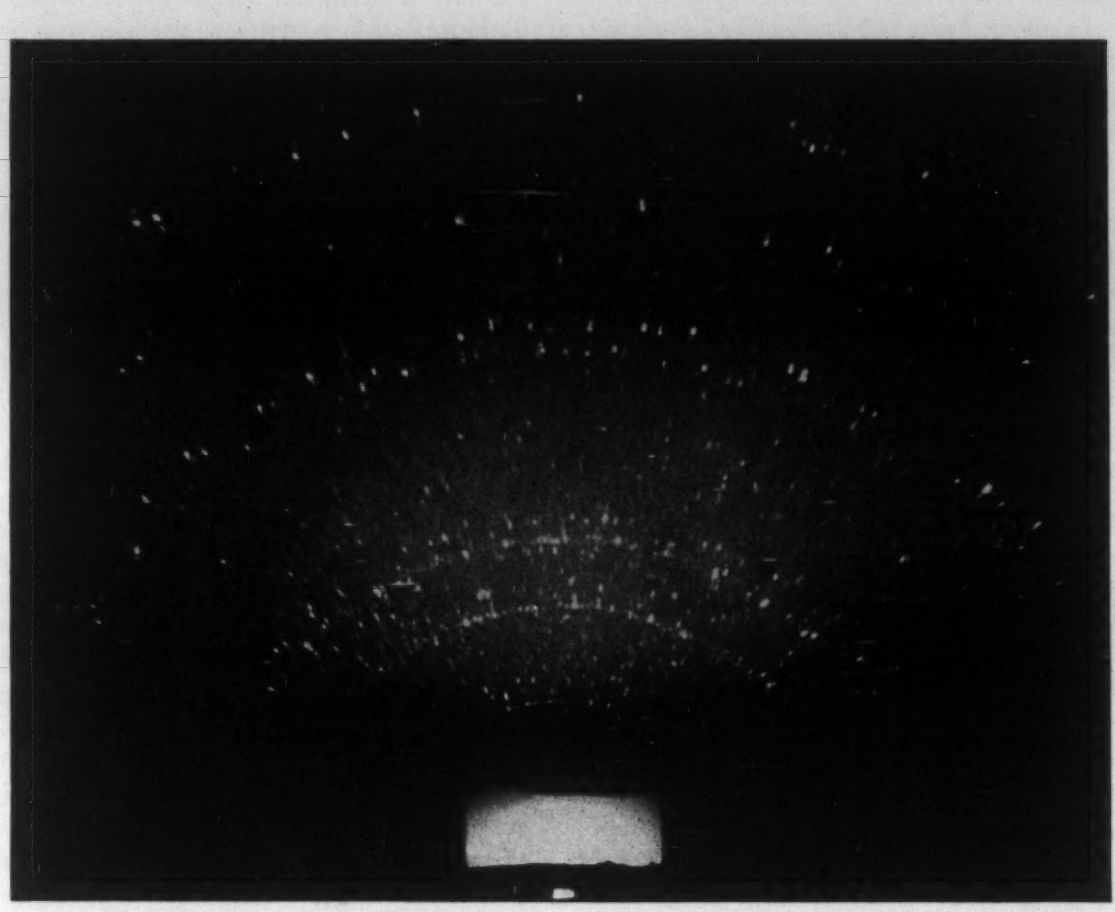


Fig. 1.—"Reflection" type of diffraction pattern taken across the direction of rolling on an annealed sample of aluminum

Wever and Schmidt have published a series of papers[4,5,39] in which they discuss the mechanism of the cold deformation of metals based on X-ray orientation studies. In their first paper,[39] on the basis of an X-ray study of the structures produced by cold rolling of aluminum, copper and silver, they conclude that the results of Mark and Weissenberg on the orientation structure of the face centered cubic metals represent a condition of incomplete rolling and that the final predominating structure depends on the type of mill and on the method of rolling. In later papers[4,5] based on X-ray studies of orientation in aluminum, they confirm this conclusion and show that no satisfactory derivation can be made on the basis of an intercrystalline gliding mechanism. It is interesting to note that they made an unsuccessful attempt to explain the structure found on the basis of a slippage along the (111) plane. They find that the textures produced by rolling are frequently not duplicated and conclude that this is due to slight but important differences in rolling technique. To avoid such differences these investigators closely simulated the rolling process by compressing parallelepipeds of aluminum in such a manner as to permit flow in only one direction. The resulting structures were studied by means of X-rays for preferred orientation. As a result of this study the conclusion was reached[40] that, "The plastic deformation of a polycrystalline aggregate proceeds by the functioning of a fine mechanism of deformation of the crystallites, excluding the inconsequential displacement at the grain boundaries. The deformation of the individual grain is not rigidly forced from without but follows from its accidental location and shape and from the concurrence of the different slip movements and "bendings" in all the neighboring grains and it is the super-position of these individual deformations in certain larger regions that forces the external deformation." along the (111) planes, but there are other factors entering in the effects of which cannot be predicted.

III. EXPERIMENTAL

a. Apparatus.

TWO types of apparatus were used for the patterns taken during this research. One was especially built for taking X-ray patterns by the pinhole method. It consisted of a pinhole system in the side of a lead box, enclosing a rigidly supported and properly aligned X-ray tube, and a suitable device for holding an X-ray film in the proper position opposite the pinholes. The other was a diffraction apparatus[41] built by the General Electric Company. The source of the radiation in each of these sets was a water-cooled Coolidge tube having a molybdenum target. It was operated at 30 kilo volts, giving the radiation for the K series of molybdenum. For the work on aluminum, nickel and copper, and for part of the work on silver, substantially all radiation other than molybdenum K-α was removed from the X-ray beam by means of the customary ZrO_2 filter.

To aid in the interpretation of the "reflection" type diffraction pattern an adjustable mounting was built, for holding a crystal lattice model rigidly in any position.

b. Samples Studied.

The sample of aluminum used was furnished by the Aluminum Company of America, in the form of a cast ingot. The chemical analysis of this sample is given in Table 1.

The sample of nickel used was furnished to us in the form of an annealed sheet by the International Nickel Company. The chemical analysis is given in Table 1.

The sample of copper used was furnished in the form of an

unannealed sheet by the American Brass Company. The chemical analysis is given in Table 1.

The sample of silver was "fine" bar silver. Its exact purity was not known, so a powder diffraction pattern was made of it, using a technique,[42] which is adapted for securing patterns for precision measurements. This pattern was measured in the usual way and the lattice parameter was determined in terms of the interplanar spacings by a precision method described by Davey.[42] These results gave a satisfactory check with those given[18] for silver 99.9% pure.

Table 1.—Chemical Analyses of Aluminum, Nickel and Copper*

Aluminum		Nickel		Copper	
Al	99.80%	Ni	99.06%	Cu	99.951%
Si	0.05%	Co	0.38%	Ag	Trace
Fe	0.03%	Cu	0.12%	As	0.0004%
Cu	0.02%	Si	0.04%	Sb	0.002%
Mn	Nil	S	0.005%	Pb	0.001%
Ti	Nil	Fe	0.014%	Sn	0.000%
		Mn	0.13%	Fe	0.0014%
		C	0.12%	Ni	0.004%
				Bi	0.000%
				Se	0.0005%
				Te	0.0003%
				S	0.0024%
				O	0.0286%

* These analyses were made in the laboratories of The Aluminum Company of America, The International Nickel Company, The American Brass Company, respectively.

c. Annealing Treatment of Samples.

It was desirable to be able to cold roll the available sample of aluminum and then remove all traces of preferred orientation by a suitable annealing treatment. X-ray investigations[32,43,44] on the recrystallization process in aluminum have shown that aluminum recrystallizes in two stages. Annealing at a low temperature alters the directional orientation due to cold work, but does not remove it. Annealing at a higher temperature gives a random arrangement. This is in agreement with commercial practice as Anderson in his book[45] states that commercial annealing is usually carried out at 350° to 500° C. and that short periods at the higher temperatures are preferable. An X-ray examination of a severely rolled sample of aluminum which had been annealed for 30 minutes *in vacuo*, at 500° C. showed a completely random orientation. Fig. 1 is a "reflection" type of diffraction pattern taken across the direction of rolling of a sample which had been given this annealing treatment. The spotted appearance is due to a large grain size, while the regular distribution demonstrates a chaotic arrangement. A comparison of this figure with Fig. 4, which is a "reflection" pattern taken with the X-rays impinging across the direction of rolling of a sample which had been annealed and then severely cold rolled, shows the effect of this annealing treatment in removing preferred orientation. This annealing procedure was adopted as standard for aluminum.

The sample of nickel used was annealed in the laboratory of the International Nickel Company, using their standard procedure. This consisted in keeping the sample at a temperature between 650° and 800° C. for a long enough period to insure a thorough heating throughout. This is done in air in the absence of air currents and of sulphur. An X-ray examination of this sample showed it to have a random orientation.

As in the case of aluminum it was necessary to secure an annealing treatment for copper which would produce a completely random orientation. X-rays[32,36] have shown that a temperature of 800° C. removes all traces of preferred orientation from copper. It was found that a sample which had been annealed for 30 minutes at 800° C. in a vacuum, showed completely random orientation on X-ray examination. This treatment was adopted as standard for copper.

As with aluminum and copper it was necessary to have an annealing treatment for silver which would produce a completely random orientation. Glocker and his co-workers[29,30,31,32] have shown that silver, like aluminum, shows two transition stages. The first transition is from the original oriented condition to an arrangement with the (112) plane parallel to the plane of rolling at temperatures from 200° to 212° C. This condition remains unchanged for all temperatures below 750° C. Above this temperature a transition occurs which gradually results in a completely random arrangement of the grains in the metal. Obviously then it was necessary to anneal at some temperature above 750° C. To determine the proper procedure a series of films were made on a trial and error basis. As a result a standard annealing technique was selected at 30 minutes heating at 900° C. in an atmosphere of hydrogen.

d. Rolling Treatment of Samples.

The original sample of aluminum was in the form of a cast ingot. A sheet 0.5 cm. in thickness was cut off the bottom of this ingot and reduced to the thickness of 0.211 cm. by three passes through the rolls. This sample was then annealed in hydrogen for 30 minutes at 450° C. It was then given 10 successive passes through a set of rolls of the usual design, having rolls $2^1/_4$ inches in diameter. The rolling was stopped at 10 passes because the sample was extremely brittle after 10 passes, causing difficulty by breaking during the rolling. It was found besides that it would have been difficult to secure "reflection" type diffraction patterns from samples thinner than Sample 11 (0.05 cm.) partly because of the low diffracting power of aluminum, and partly because of danger of getting a diffraction pattern from the under face of the sheet. The metal was passed through the rolls slowly enough so that no appreciable rise in temperature could be felt in the metal as it came from the rolls. This point was given careful attention to insure that there could be no effect of local heating on the orientation of the crystal fragments in the metal sheet. Care was taken to see that the samples went through the rolls in the same direction for each pass and that each sample went through at right angles to the axes of the rolls. A piece of metal suitable for a reflection sample was cut off and saved after each pass, each sample being labeled to show exactly how it went through the rolls. Each of these samples was trimmed so that its edges were exactly parallel and perpendicular to the direction of rolling. The thickness of each of these samples of aluminum is given in the third column of Table 2.

Table 2.—Rolling Series for Aluminum, Nickel, Copper, and Silver

Sample Number	Total Number of Passes through Rolls	Aluminum Series Thickness, cm.	Nickel Series Thickness, cm.	Copper Series Thickness, cm.	Silver Series Thickness, cm.
1	0 (Annealed)	0.211	0.317	0.240	0.145
2	1	0.155	0.300	0.238	0.134
3	2	0.137	0.277	0.219	0.113
4	3	0.132	0.262	0.198	0.111
5	4	0.124	0.254	0.168	0.100
6	5	0.114	0.218	0.147	0.070
7	6	0.102	0.198	0.140	0.044
8	7	0.095	0.178	0.114	0.024
9	8	0.086	0.162	0.102	0.014
10	9	0.069	0.142	0.094	
11	10	0.050	0.132	0.079	
12	11		0.117	0.061	
13	12		0.102	0.051	

The original sample of nickel was in the form of an annealed sheet 0.317 cm. thick. It was given 12 successive passes through the rolls, using an identical procedure as that described for aluminum. The thickness of each sample of this rolling series for nickel is given in the fourth column of Table 2.

The original sample of copper was in the form of a cold rolled sheet 0.240 cm. thick. This sample was annealed at 800° C. for 30 minutes in a vacuum. It was then given 12 successive passes through the rolls using exactly the same procedure as described for aluminum. The thickness of each sample is given in the fifth column of Table 2.

The original sample of silver was a cold rolled bar 0.318 cm. thick. This bar was further rolled until its thickness was reduced to 0.145 cm. It was then annealed in hydrogen for 30 minutes at 900° C. This sample was then given 8 successive passes through the rolls, using the procedure described for aluminum. The thickness of each sample of the series is given in the sixth column of Table 2.

e. Technique Used for Securing "Reflection" Type Diffraction Patterns.

The diffraction patterns used for the determination of orientation in this work were secured by the diffraction of X-rays from the surface layers of crystal fragments of metal sheets, in an analogous manner to the reflection of light from a mirror. An X-ray beam defined by a system of fine pinholes was allowed to impinge on a sheet of metal placed at an angle of approximately 20° to it and in a position such that the upper edge was horizontal. The exact setting of the specimen could be determined at once from an examination of the photographic film for the given specimen. For securing the diffraction patterns with the X-rays impinging across the direction of rolling, the samples were always placed with the end of the sample which went through the rolls first to the right when viewed from the X-ray tube. For securing the diffraction patterns with the X-rays impinging along the direction of rolling the samples were always set up with the end of a sample which went through the rolls first away from the X-ray tube. The absorption of Ag, Ni and Cu for the K-α rays for the Mo is such that under ordinary circumstances the X-ray intensity is reduced to not more than 8% of its original value by traversing a depth of 0.01 cm. (0.004 in.). Since the apparent coefficient of absorption is increased markedly at the diffracting angle, the actual intensity at this depth below the surface is considerably less than this. Similarly the X-rays diffracted from this depth are reduced to less than 8% of their initial intensity by the time they reach the surface. The diffracted beam from a distance 0.01 cm. (0.004 in.) below the surface (measured along the path of the beam) is therefore much less than 0.08 × 0.08 as intense as that from the surface. It is reasonable to assume that for these metals the only diffracted beams intense enough to be seen on the photographic film come from a layer not more than 0.001 cm. (0.0004 in.) deep, measured in a direction perpendicular to the surface. In the case of Al, the smaller density and smaller apparent coefficient of absorption make it reasonable to assume a considerably greater limiting distance, say about 0.02 cm. (0.008 in.). But even here we must remember that the surface layers produce very much more effect on the photographic film than the layers at the depth of 0.02 cm. We estimate the effective depth represented by our diffraction patterns of Al to be about 0.01 cm. (0.004 in.). In any case, in the absence of an etching reagent which would etch down evenly without respect to the orientation of individual grains, we can only say that our results represent the closest approximation to the facts which we can get with X-rays from Mo. It was found desirable to place a sheet of lead of the same dimensions underneath the thinner samples of Al to absorb the portion of the X-ray beam which penetrated the sample, in order to cut out back-radiation. When the lead was used in this way, it did not introduce a diffraction pattern of the lead on the photographic film. This is consistent with the argument just given in favor of a not-too-great limiting depth in the Al. The diffraction patterns were recorded on 5 × 7 in. Eastman Diaphax X-ray films enclosed in light proof holders. The holder, with its contained film, was mounted vertically at a distance of 5 cm. from the spot where the X-ray beam impinged on the sample and in such a position that the undeviated X-ray beam would have struck it about an inch from the bottom and halfway between the two sides. This set-up is illustrated in Fig. 2. The film in this position was exposed long enough to secure a satisfactory diffraction pattern (usually about 72 hours). The sample was then removed from the path of the beam, the film being left in place, and the undeviated beam was allowed to strike the film for ten seconds to produce the center spot. Filtered radiation was used in most cases, although the unfiltered rays were used in some cases with silver to reduce the exposure time to a minimum. Diffraction patterns of the "reflection" type are illustrated in the form of positive prints in Figs. 1, 4, 5, 6, 7, 8, 9, 10 and 11.

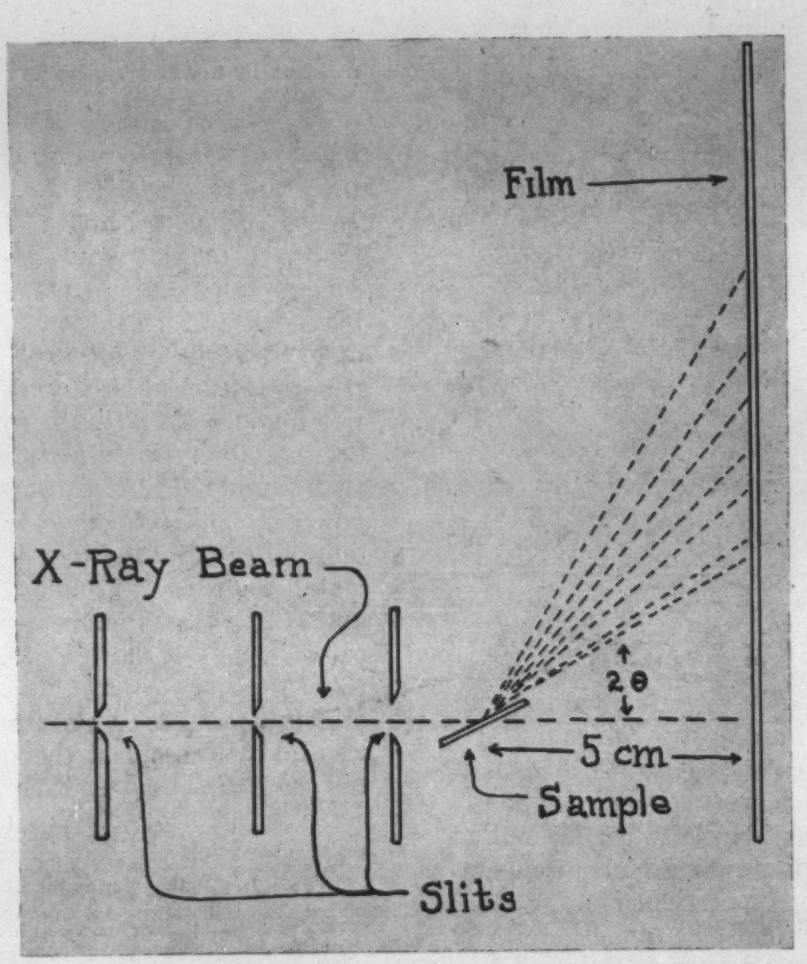


Fig. 2.—Diagram of experimental set-up for securing diffraction patterns of the "reflection" type

f. Diffraction Patterns Made.

Two diffraction patterns were made of each of the samples listed in Table 2. One of the two patterns was taken with the sample so placed that a plane perpendicular to the sheet of metal included the incident beam and the direction of rolling, or in other words, was taken so that the incident beam impinged along the direction of rolling of the specimen. The other pattern was made with the X-ray beam impinging across the direction of rolling. Two such patterns from each sample furnished sufficient information to determine for our purposes the preferred ranges of positions of the crystal fragments in the surface of the sheet of metal.